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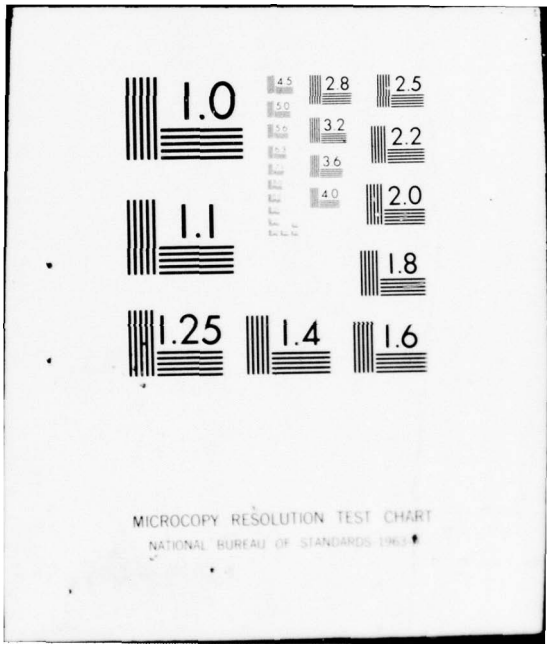
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NATIONAL BUREAU OF STANDARDS 1963

Publication 1042-01-1-1310

FINAL REPORT
REVISION OF TECHNICAL MANUAL
"SPECTROMETRIC OIL ANALYSIS PROGRAM (SOAP) EVALUATION CRITERIA"

November 1974

Prepared for
United States Air Force
San Antonio Air Logistics Center
Kelly Air Force Base, Texas 78241

ARINC RESEARCH CORPORATION

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(1)

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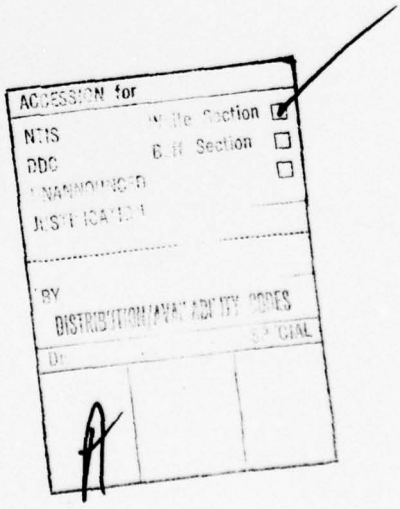
FOREWORD

This final report is submitted to the United States Air Force (USAF) by ARINC Research Corporation in fulfillment of the requirements of Contract F09603-73-A-0933-SA01. It presents a revision of the Technical Manual *Spectrometric Oil Analysis Program (SOAP) Evaluation Criteria* (T.O. 42B2-1-10).

We wish to acknowledge the complete cooperation of all persons contacted during the course of this study, including those in Headquarters USAF, Air Force Logistics Command, San Antonio Air Logistics Center, Tactical Air Command, Air Training Command, Air Force Inspection and Safety Center, and the Aerospace Research Laboratories. Their willing support in providing all available data and information made completion of this study possible.



ABSTRACT

This report presents the results of a study of the U.S. Air Force Spectrometric Oil Analysis Program. The study consisted of review, evaluation, and documentation of data for revision of the Technical Manual *Spectrometric Oil Analysis Program (SOAP) Evaluation Criteria* (T.O. 42B2-1-10). The purpose of the revision is to provide the SOAP laboratory analyst with more positive guidance, and to ensure ease of use of the evaluation criteria for the equipments considered in this study. The report covers development of a methodology, data collection, data analysis, and formulation of evaluation criteria. Specific problem areas observed during the study are identified, and recommendations for their solution are presented.

SUMMARY

1. INTRODUCTION

Under USAF Contract F09603-73-A-0933-SA01, ARINC Research Corporation conducted a study of the U.S. Air Force Technical Manual *Spectrometric Oil Analysis Program (SOAP) Evaluation Criteria* (T.O. 42B2-1-10). The purpose of the study, performed for the SOAP Management Office at San Antonio Air Logistics Center, was to revise the Technical Manual for selected equipments (1) to offer more positive guidance to the SOAP analyst and (2) to ensure ease of use of the developed evaluation criteria.

2. CONDUCT OF THE STUDY

Documentation describing methodologies and formats used to establish procedures for spectrometric oil analysis was obtained from USAF, Navy, and commercial-airline sources. This information was reviewed and evaluated for use in developing new SOAP evaluation criteria. After a critical examination of existing methodologies and ideas, a proposed methodology and a format were developed on the basis of wearmetal-particle buildup. Specific Air Force equipments were selected, and all available SOAP-identified maintenance actions on these equipments were collected and screened for their validity and usefulness in this study. The SOAP data were than statistically analyzed by means of a regression-analysis technique.

3. RESULTS

The results of the statistical analyses were used to develop new criteria for evaluating the SOAP-monitored equipments considered in this study.

Data-analysis plots were prepared and equipment malfunctions were tabulated for each wearmetal element for which sufficient data were available for statistical analysis. (See Appendix A.)

The Technical Manual *Spectrometric Oil Analysis Program (SOAP) Evaluation Criteria* was revised on the basis of historical data. The manual

revisions are presented as Appendix B to this report. Each equipment considered in this study is represented in the manual by a set of "decision tables" for evaluation of SOAP results. A diagnostic guide, or explanatory text, is also offered for each equipment (1) to provide special instructions, and (2) to assist the laboratory analyst in classifying an oil-wetted component as suspect on the basis of increasing wearmetal trends.

4. CONCLUSIONS AND RECOMMENDATIONS

Conclusions and recommendations resulting from this study are summarized as follows:

- For equipments that exhibit high oil consumption or have small oil-tank capacities, wearmetal buildup trends can best be analyzed by graphically plotting element concentration values (ppm) versus equipment operating hours in addition to using the wearmetal Decision Tables.
- Whenever wearmetal concentration increases beyond the "A" code value range, as defined in the Decision Tables, it is recommended that equipment oil not be changed.
- Consideration should be given to reducing the number of laboratory recommendation codes in T.O. 42B2-1-9 to those cited in the Decision Tables.
- All SOAP data (for the equipments considered in this study) accumulated following the publication of this report should be reviewed, evaluated, and analyzed periodically.
- By use of the methodology and format set forth in this report, decision criteria for the balance of USAF SOAP-monitored equipments should be developed and incorporated in the revised Technical Manual.
- The revised Technical Manual for SOAP evaluation criteria should be indexed by equipment and end item for easy reference.
- The procedure for reporting all SOAP-related maintenance actions to the laboratory should be improved to provide greater accuracy.
- A procedure should be initiated for editing SOAP data to provide accuracy, uniformity, and clarity to Unit Failure Histories recorded in the SAALC Computer Data Bank.
- As a result of observed differences in wearmetal trends, separate decision criteria should be considered for F-101/F-102 power plants when additional data become available.
- Consideration should be given to the use of a "quick look" oil analysis technique to reduce laboratory and organizational maintenance workloads by decreasing the number of samples processed. Such a technique, using the Mobil Fotoscope, is currently being employed by National Airlines.

CONTENTS

CONTENTS (continued)

CHAPTER ONE

INTRODUCTION

1.1 GENERAL

Under USAF Contract F09603-73-A-0933-SA01, ARINC Research Corporation performed a study of the evaluation criteria for the U.S. Air Force Spectrometric Oil Analysis Program (SOAP). Technical cognizance was vested in the USAF SOAP Management Office of the Service Engineering Division, San Antonio Air Materiel Area (SAAMA)*, San Antonio, Texas. The study, started on 29 June 1973, consisted of the review, evaluation, and documentation of data for revision of the Technical Manual *Spectrometric Oil Analysis Program (SOAP) Evaluation Criteria* (T.O. 42B2-1-10). The purpose of the revision is to provide the SOAP laboratory analyst with more positive guidance, and to ensure ease of use of the evaluation criteria for the equipments considered in this study.

1.2 CONDUCT OF THE STUDY

To complete the program, it was necessary to develop a methodology and format for establishing criteria (Phase I) and to develop specific equipment evaluation criteria (Phase II).

1.2.1 Phase I: Development of Methodology and Format

The primary objective of Phase I was to develop (1) a methodology for evaluating oil analysis readings on the basis of historical data, and (2) a format for presenting to the laboratory analyst decision criteria for making maintenance recommendations.

1.2.1.1 Collection of Documentation

Documentation describing methodologies and formats previously used to establish criteria for spectrometric oil analysis was collected from various sources.

1.2.1.2 Review of Methodologies and Formats

The documentation was reviewed; each methodology used to develop criteria was examined, together with the format used to present the criteria. Particular attention was given to how effectively laboratory analysts could use the evaluation criteria.

*Currently San Antonio Air Logistics Center.

1.2.1.3 Development of Proposed Methodology

After a critical review of existing methodologies and ideas, a proposed methodology and format were developed on the basis of wearmetal particle buildup in equipment oil systems.

1.2.2 Phase II - Development of Equipment Criteria

The purpose of Phase II was to develop specific equipment criteria, using the methodology developed in Phase I.

1.2.2.1 Data Collection

Historical data were obtained from the U.S. Air Force for the equipments listed in Chapter Two, Table 2. Sources of these data are discussed in Section 2.3.3.

1.2.2.2 Data Analysis

Available historical data were used to identify the critical wearmetal elements and determine the rate of change in particle buildup of the critical elements.

1.2.2.3 Criteria Formulation

The rate of change in wearmetal particle buildup for the various equipments was used, with the methodology developed during Phase I, to establish specific evaluation criteria for each equipment.

In addition, the special instructions of the Technical Manual were updated, where applicable; these appear as diagnostic guidance opposite the evaluation criteria for each equipment in Appendix B.

1.3 ORGANIZATION OF REPORT

Chapter Two describes the approach taken in developing the revision to the Technical Manual for selected Air Force equipments -- including the literature survey, methodology development, data collection, and data analysis.

The results of the study are presented in Chapter Three, with particular attention given to the formulation of the evaluation criteria and use of the developed "decision tables" and diagnostic guides. Conclusions and recommendations based on the observations made during this effort are given in Chapter Four.

Appendix A presents the data-analysis plots for equipments with sufficient data for statistical analysis. Appendix B provides the "decision tables" and diagnostic guides for the equipments considered in this study.

A bibliography of documents used during the study is presented in Appendix C.

CHAPTER TWO

APPROACH

2.1 SURVEY

ARINC Research Corporation surveyed available literature on the techniques used for evaluating equipment condition through spectrometric oil analysis. Twenty-three documents obtained through the National Technical Information Service of the U.S. Department of Commerce were reviewed. Documented evaluation techniques from the Tactical Air Command (TACM 66-1) and the U.S. Navy (NARFP-P-12) were studied in detail for applicability to this effort. The overall conclusion from the literature survey was that there is no known existing technique distinctly suitable for Air Force use which is based upon engine historical data and presents criteria for action in a format easily used by analyst personnel.

In addition to surveying the literature, ARINC Research representatives consulted the following organizations:

- USAF SOAP Manager
- Headquarters AFLC
- Headquarters TAC
- Headquarters ATC
- USN Technical Support Center
- American Airlines
- Trans World Airlines
- National Airlines

Discussions were held regarding existing evaluation methods and recommended means of developing evaluation criteria. The airlines visited are using spectrometric oil analysis as one element of an overall on-condition (or condition-monitored) maintenance program. Their sampling intervals are substantially longer than those of the Air Force, and there are no documented evaluation criteria.

An interesting technique was discussed at National Airlines, where a Mobil Fotoscope is used for a "quick look" oil analysis of engines and Auxiliary Power Units (APUs). Spectrometric analysis is performed only if the light transmissivity falls below a prescribed level, indicating the presence of some form of oil contamination. This approach has greatly reduced the number of samples processed spectrometrically, while a substantial reduction in unscheduled removals has been achieved. One side benefit of the technique is that it provides indication of oil degradation due to the leakage of hot air past faulty seals. Although this technique is a qualitative one, it appears worthy of some investigation as an adjunct to spectrometric analysis. If usable, it could reduce the laboratory and organizational maintenance workloads by reducing the number of oil samples processed.

2.2 DEVELOPMENT OF THE METHODOLOGY

2.2.1 Development of Evaluation Criteria

The following were the primary factors considered in developing a technique for evaluating SOAP data and prescribing courses of action:

- The technique must be easy to use by USAF enlisted or civilian personnel with a minimum of training.
- The technique must utilize data readily available to the analyst.
- The criteria for action should be consistent and unambiguous.
- The prescribed actions should be commensurate with the best possible estimate of equipment condition at the time of analysis.

The technique developed on the basis of these factors utilizes historical data to predict future performance and prescribes a course of action based on that prediction. The basis for arriving at such a prediction is the wearmetal-concentration-buildup curve.

During an earlier study* it was demonstrated that data existed to permit wearmetal-concentration-buildup curves to be plotted for a given type of equipment. These curves, derived from equipment SOAP records (AFTO 119A Forms), showed wearmetal concentrations plotted as a function of operating hours prior to detection of impending failure. In order to plot such curves, it is necessary to have SOAP records for a number of similar equipments, showing wearmetal readings from the time the equipment was considered to be performing normally through the time the laboratory recommended that the equipment be inspected or removed from service.

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*_Study of the U.S. Air Force Spectrometric Oil Analysis Program_, 22 February 1972, ARINC Research Publication C15-01-1-1162.

The methodology for developing SOAP evaluation criteria utilizes wearmetal-concentration-buildup curves as the basis for predicting the rate at which concentrations will build up in a typical equipment of a given type. From the predicted rate of buildup it can be estimated how many operating hours remain until a discrepancy is likely to be detected as a function of some present concentration level. These estimates can then be used to prescribe courses of action based on present spectrometric readings.

2.2.2 Development of Buildup Curves

For each equipment with a verified discrepancy identified by SOAP, the wearmetal readings were tabulated as a function of operating hours prior to SOAP laboratory detection. Table 1 is an example of such a tabulation for iron (Fe).

Table 1. SAMPLE TABULATION

Hours Since Overhaul	Fe (ppm)	Operating Hours Prior To Detection
475	3	106
484	3	97
495	3	86
503	3	78
509	3	72
517	4	64
525	4	56
532	4	49
540	5	41
546	6	35
550	6	31
559	6	22
565	7	16
572	8	9
575	9	6
579	11	2
581	13	0

For the example shown, the laboratory recommended maintenance action at an iron reading of 13 parts per million (ppm), which resulted in verification of a discrepancy. This is identified as the point of detection. The hours prior to detection were then obtained by subtracting the "hours since overhaul" for each reading from the corresponding value at the point of detection. This step is necessary in order to normalize the data for various equipments to a common time base. A plot of the data from Table 1 results in the wearmetal-concentration-buildup curve shown in Figure 1.

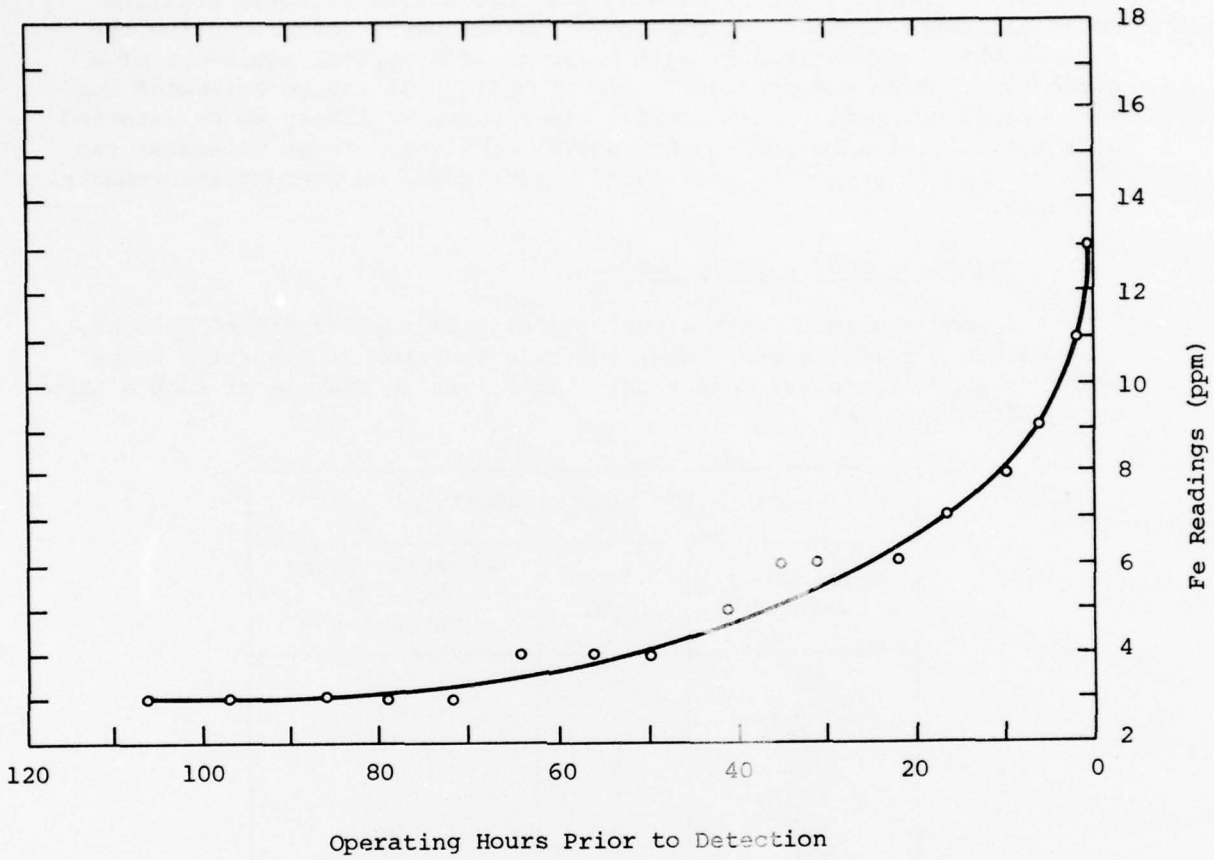


Figure 1. SAMPLE WEARMETAL-CONCENTRATION-BUILDUP CURVE

This method is then repeated for each available equipment history. After the data for a given spectrometer and wearmetal element are compiled, a statistical analysis is performed to derive the best curve fit for each set of data (see Section 2.4).

2.3 DATA COLLECTION

2.3.1 SOAP Data Considered

Data were compiled on equipments in which an impending failure or discrepancy had been detected by SOAP. These historical data consisted of wearmetal-element readings, hours since overhaul and hours since oil change at the time of the reading, laboratory recommendations, and maintenance information pertinent to discovery and verification of a discrepancy.

2.3.2 Equipments Considered

SOAP data for this study were obtained for the U.S. Air Force equipments listed in Table 2.

Table 2. SUMMARY OF AIR FORCE EQUIPMENTS CONSIDERED IN THIS STUDY

Equipment	End Item	Equipment	End Item
J33-35	T-33	TF39-1	C-5
J57-13/23/55	F-101/F-102	TF41-1	A-7
J57-19/43/59	B-52/C-135	T53-11/13	H-43/H-1
J57-21	F-100	T56-7/9	C-130
J60-3	T-39	T58-1/5	H-3
J69-25	T-37	T58-3	H-1
J75-17	F-106	T76-10/12	OV-10
J75-19	F-105	T400-CP-400	H-1
J79-11	F-104	IO-360	O-2
J79-15/17	F-4	R2800 - All Series	C-118/C-131/T-29
J85-5/17	T-38/A-37	GTCP85-106	C-141(APU)
TF30 - All Series	F-111/FB-111	GTCP85-397	M32A-60
TF33 - All Series	B-52/C-135/C-141	GTCP165-1	C-5(APU)

2.3.3 Sources of Data

Various sources were drawn upon in collecting the SOAP-identified maintenance-action data used in this study:

- SAAMA* Computer Data Bank printouts. These provided SOAP Unit Failure Histories for the period January 1971 through January 1974.
- AFTO 119A Forms. SOAP data recorded on 119A Forms were screened for selected equipments covering the period September 1972 through September 1973 for the following commands:
  - Aerospace Defense Command (ADC)
  - Air Force Logistics Command (AFLC)
  - Air National Guard (ANG)
  - Military Airlift Command (MAC)
  - Pacific Air Command (PAC)

*Currently San Antonio ALC.

- Strategic Air Command (SAC)
- Tactical Air Command (TAC)
- United States Air Force Europe (USAFE)

Other 119A Forms were obtained from a previous study conducted by ARINC Research Corporation.*

- RCS: K-30 Monthly SOAP Reports. These cover only TAC SOAP efforts for the base laboratories listed in Table 3. Reporting periods ranged from January 1969 to November 1970.

Table 3. TAC BASE LABORATORIES CONTRIBUTING RCS: K-30 SOAP DATA REPORTS

Base Laboratory	Location
Cannon AFB	New Mexico
Dyess AFB	Texas
George AFB	California
Holloman AFB	New Mexico
Little Rock AFB	Arkansas
Lockbourne AFB	Ohio
Myrtle Beach AFB	South Carolina
Pope AFB	North Carolina
Seymour Johnson AFB	North Carolina

2.4 DATA ANALYSIS

2.4.1 Background

The compiled historical data were used to identify the critical wearmetal elements and determine the rate of change in particle buildup of these critical elements. The collected data were analyzed to accomplish the following:

- Identify the critical wearmetal element(s) for each equipment. It was noted that in a majority of the SOAP-identified discrepancies, the iron wearmetal predominated. In other SOAP-identified discrepancies, the iron content did not change appreciably, although aluminum, chromium, copper, and magnesium did increase significantly.
- Determine the rate of change of wear of the critical elements for SOAP-detected discrepancies, identifying the point at which "normal" wear accelerates to an increasing wear rate. (This is treated in greater detail in Section 2.4.3.)

**Study of the U.S. Air Force Spectrometric Oil Analysis Program*, 22 February 1972, ARINC Research Publication C15-01-1-1162.

- Identify and substantiate peculiar characteristics of the equipments that have an impact on the wearmetal-concentration readings, such as oil-system capacity, high oil consumption of equipment, and types of material used in oil-wetted parts. The results of this analysis have been incorporated into the special instructions of the diagnostic guidance presented in Appendix B for each equipment.

2.4.2 Data Reduction and Analysis Method

The data for equipment histories having SOAP-related maintenance actions were screened manually. They were accepted as valid and useful for this study if they met the criteria and provided the information described in the following subsections. Failure to meet any one of these requirements (with the exceptions noted below) resulted in rejection of the data.

2.4.2.1 Type Specification

It was necessary for the data to specify equipment type, serial number, and end-item use. Spectrometer type was also required:

- (B) - Baird-Atomic A/E 35U-1 (Emission)
- (C) - Baird-Atomic A/E 35U-3 (Emission)
- (Q) - Perkin-Elmer 303/305 (Atomic Absorption)

2.4.2.2 "Hours Since"

"Hours Since Overhaul" or "Hours Since Oil Change" had to be provided in continuous and chronological order. It was not necessary for both of these parameters to be present simultaneously; but one had to exist for each equipment history.

2.4.2.3 Laboratory Recommendation

One of the following codes (per T.O. 42B2-1-9) was required:

- K - Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded.
- T - Ground unit, examine for suspected discrepancy. Advise laboratory of findings.

As an exception to this criterion, the AFTO 119A Forms and RCS: K-30 monthly SOAP reports were evaluated on an individual basis since they did not generally specify codes K and T. Recommendations for maintenance action were usually given in note form in the "Remarks" area of the 119A Form, while the RCS: K-30 reports recorded only those equipments under maintenance inspection as directed by SOAP.

2.4.2.4 Order of Wearmetal-Concentration Values

Wearmetal-concentration values (ppm) had to be in a logical and systematic order and be reasonably consistent with time (hours since overhaul or oil change). Values upon which the laboratory based a K or T recommendation had to meet or exceed the T.O. 42B2-1-10 guidelines or, if they did not, reflect significant trends.

2.4.2.5 "How Discovered"

For the failure to be considered valid, it must have been identified by SOAP.

2.4.2.6 "Component"

It was required that a specific component be identified as having malfunctioned. However, the AFTO 119A Forms usually specified only a request for maintenance action based on wearmetal-concentration values (ppm). Seldom were specific malfunctioning components recorded. An exception was made, and AFTO 119A data that met the other criteria were used in this study, but with "Unknown" listed for component failure when applicable.

2.4.2.7 "How Malfunction"

It was necessary that a specific failure mode be stated (e.g., disintegrated, chipped or pitted, worn beyond limits). However, in AFTO 119A data, as discussed above, the failure mode was usually not specified. Again, an exception was made, and AFTO 119A data that met the other criteria were used.

2.4.3 Regression Analysis

The rate of change in wearmetal-element buildup as discussed in Section 2.4.1 was used with the methodology described in Section 2.2 to establish specific criteria for each equipment. A regression-analysis technique was employed to perform a statistical analysis of SOAP data on equipments for which sufficient data were available. Table 4 summarizes the data used in the statistical regression analyses. It can be seen that the availability of data for analysis of wearmetal elements other than iron was poor and that for several of the equipments there were insufficient data for all elements. However, sufficient data did exist to permit a statistical regression analysis on several of the elements for many of the equipments.

The data for a specified equipment/end item/spectrometer/wearmetal element were divided into two groups: (1) data describing "normal" wear and (2) data representing "abnormal", or increasing, wear. Rather than fit a polynomial over the entire range of data, it is possible to use an estimating procedure* to fit a straight line through each of the data groups and identify the point at which the two lines intersect. It is this point of intersection,

*Details of the procedure can be found in "Fitting Segmented Curves Whose Join Points Have To Be Estimated", by Derek J. Hudson, *American Statistical Journal*, December 1966 (pp. 1097-1129).

Table 4. SUMMARY OF DATA USED IN STATISTICAL REGRESSION ANALYSES

Equipment	End Item	Fe			Ag			Al			Cr			Cu			Mg			Ni			Ti		
		B	C	Q	B	C	Q	B	C	Q	B	C	Q	B	C	Q	B	C	Q	B	C	Q	B	C	Q
J33-35	T-33			X														X	X						
J57-13/23/55	F-101/F-102		X	(1)											X										
J57-19/43/59	B-52/C-135		X	X														X							
J57-21	F-100			(1)																					
J60-3	T-39			X														(3)	X						
J69-25	T-37		X	X								X			X										
J75-17	F-106		(2)	(2)						(2)															
J75-19	F-105		(2)	(2)						(2)															
J79-11	F-104		X												X										
J79-15/17	F-4	X	X	X											X	X		X							
J85-5/17	T-38/A-37		X	X											X			X	X						
TF30 - All Series	F-111/FB-111	X	X	X																					
TF33 - All Series	B-52/C-135/C-141		X																						
TF39-1	C-5																								
TF41-1	A-7		X												X										
T53-11/13	H-43/H-1																								
T56-7/9	C-130		X	X											X	X	(3)	X	X						
T58-1/5	H-3																								
T58-3	H-1																								
T76-10/12	OV-10																								
T400-CP-400	H-1																								
IO-360	O-2																								
R2800 - All Series	C-118/C-131/T-29		X						X																
GTCP85-106	C-141 (APU)		X																						
GTCP85-397	M32A-60		X	X											(3)	X									
GTCP165-1	C-5 (APU)																								

X - Sufficient data to perform statistical regression analysis

(1) - Regression analysis performed on combined data for J57-21/23 (F-100/F-102)

(2) - Regression analysis performed on combined data for J75-17/19 (F-106/F-105)

(3) - Data not suitable for performing piece-wise regression analysis; however, data sufficient to influence selection of decision criteria.

B - Baird-Atomic A/E35U-1 (Emission)

C - Baird-Atomic A/E35U-3 (Emission)

Q - Perkin-Elmer 303/305 (Atomic Absorption)

or join point, that indicates the average time prior to detection of an incipient failure and the wearmetal-concentration value at which wear rate begins to increase significantly. The solution, known as a "piece-wise", or "segmented", regression, provides for an overall least-squares fit.

Table 5 is a tabulation of the results of the "piece-wise" regression analysis. Calculated wearmetal concentration values describing the join point and element intercepts (B_0 and B_2) are rounded off to the nearest tenth of a ppm. Slopes (B_1 and B_3) describing the straight-line fits through data representing "abnormal" and "normal" wear, respectively, are truncated at the hundredth of a ppm. Similarly, the time prior to detection at the join point is computed to the nearest tenth of an hour. When the regression-analysis results for a given equipment/end item/spectrometer/wearmetal element are plotted, two intersecting straight lines are constructed as a best fit to the data.

A typical curve fit is shown in Figure 2. The curve fit is computed from the data analyzed within a specified time frame. Equipment operating hours are normalized on the basis of the time an incipient failure was detected by SOAP (see Section 2.2). Therefore, only the data for the interval from some specified time prior to detection (t) to time = 0 were considered in the analysis. This time interval is identified in Table 5 as "Data Range (Hours)."

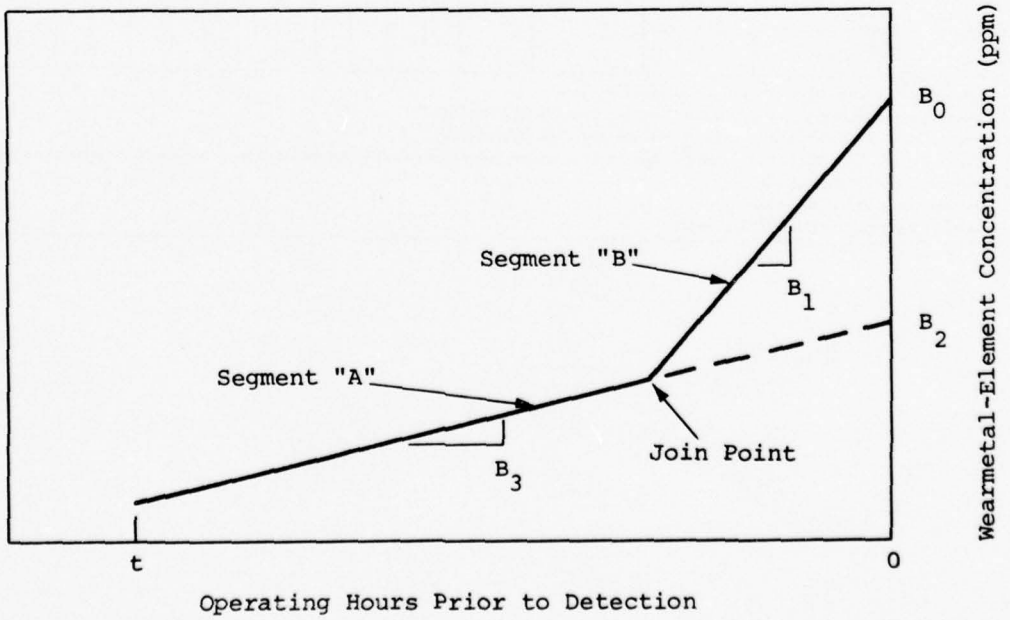


Figure 2. TYPICAL CURVE FIT FOR DATA ON A GIVEN EQUIPMENT/ END ITEM/SPECTROMETER/WEARMETAL ELEMENT

Table 5. REGRESSION-ANALYSIS RESULTS

Equipment	End Item	Instrument	Element	Data Range (Hours)	B_0 (Intercept)	B_1 (Slope)	B_2 (Intercept)	B_3 (Slope)	Join Point (ppm)	Join Point Time (Hours)
J33-35	T-33	C	Mg	30	6.3	-1.63	2.9	-0.06	2.8	2.1
		Q	Fe	30	16.0	-0.62	12.5	-0.21	10.7	8.5
		Q	Mg	30	5.4	-0.74	3.3	-0.02	3.2	3.0
J57-13/23	F-101/F-102	C	Fe	23	29.0	-2.27	14.4	-0.22	12.9	7.1
J57-13/23/55	F-101/F-102	C	Cu	20	8.6	-0.37	5.5	-0.02	5.4	9.0
J57-19/43/59	B-52/C-135	C	Fe	100	37.5	-0.82	22.5	-0.10	20.6	20.6
		C	Mg	50	14.8	-0.45	7.6	-0.08	6.1	19.3
		Q	Fe	40	20.1	-6.10	11.7	-0.06	11.6	1.4
J57-21/23	F-100/F-102	Q	Fe	15	12.3	-1.18	7.7	-0.08	7.3	4.2
J60-3	T-39	Q	Fe	50	17.8	-0.39	12.8	-0.10	11.2	16.9
		Q	Mg	40	7.8	-0.28	4.6	-0.06	3.9	13.9
J69-25	T-37	C	Fe	45	40.6	-1.24	27.6	-0.35	22.5	14.6
		C	Cr	30	18.6	-0.73	9.1	-0.14	7.0	16.0
		C	Cu	45	11.8	-0.23	10.3	-0.09	9.4	10.4
		Q	Fe	40	28.2	-1.75	19.5	-0.28	17.9	5.9
J75-17/19	F-106/F-105	C	Fe	18	33.6	-2.27	24.4	-0.04	24.2	4.1
		Q	Fe	40	15.2	-0.86	9.5	-0.09	8.9	7.1
		Q	Al	15	5.5	-0.94	2.7	-0.07	2.5	3.2
J79-11	F-104	C	Fe	21	52.3	-11.34	40.6	-0.66	40.0	1.1
		C	Cu	13	19.6	-1.09	17.7	-0.14	17.4	2.0
J79-15/17	F-4	B	Fe	39	29.0	-2.09	15.8	0	15.8	6.3
		C	Fe	50	31.8	-1.08	21.1	-0.14	19.5	11.4
		C	Cu	20	15.3	-0.81	10.6	-0.12	9.9	6.7
		C	Mg	30	16.4	-0.65	15.0	-0.28	13.9	3.8
		Q	Fe	29	21.4	-2.85	16.1	-0.36	15.3	2.1
		Q	Cu	35	7.6	-0.47	5.3	-0.10	4.7	6.0
J85-5/17	T-38/A-37	C	Fe	50	44.5	-1.49	38.8	-0.44	36.4	5.4
		C	Cu	60	10.0	-0.50	5.4	-0.02	5.3	9.4
		C	Mg	55	11.8	-0.41	9.9	-0.09	9.4	5.9
		Q	Fe	70	24.4	-0.85	17.2	-0.16	15.7	10.2
		Q	Mg	80	5.9	-0.48	5.1	-0.04	5.0	2.0
TF30 - All Series	F-111/FB-111	B	Fe	30	19.4	-5.08	8.9	-0.09	8.7	2.1
		C	Fe	14	27.8	-1.48	18.4	-0.38	15.2	8.5
		Q	Fe	45	16.9	-3.73	6.9	-0.11	6.6	2.8
TF33 - All Series	B-52/C-135/C-141	C	Fe	120	26.1	-0.91	8.0	-0.01	8.0	20.0
TF41-1	A-7	C	Fe	20	17.3	-4.09	10.3	-0.24	9.8	1.8
		C	Cu	15	17.6	-2.08	14.1	-0.33	13.4	2.0
T56-7/9	C-130	C	Fe	160	36.5	-0.84	23.2	-0.07	22.0	17.3
		C	Cu	100	14.2	-0.29	11.5	-0.06	10.9	11.4
		C	Mg	160	29.6	-0.26	24.5	-0.08	22.3	28.1
		Q	Fe	50	20.8	-0.74	15.4	-0.04	15.1	7.7
		Q	Cu	110	9.3	-0.23	6.6	-0.05	5.9	14.8
		Q	Mg	70	10.0	-0.14	7.3	-0.02	7.0	21.4
R2800 - All Series	C-118/C-131/T-29	C	Fe	110	62.5	-2.33	42.9	-0.20	41.0	9.2
		C	Al	110	24.4	-0.59	9.9	-0.04	9.1	25.9
GTCP85-106	C-141 (APU)	C	Fe	100	65.7	-11.97	42.1	-0.24	41.6	2.0
GTCP85-397	M32A-60	C	Fe	130	45.2	-1.46	26.3	-0.18	23.7	14.7
		Q	Fe	60	20.8	-0.85	14.4	-0.10	13.6	8.5
		Q	Cu	50	9.9	-0.87	3.9	-0.02	3.8	7.0

Instrument:

B - Baird-Atomic A/E35U-1 (Emission)

C - Baird-Atomic A/E35U-3 (Emission)

Q - Perkin-Elmer 303/305 (Atomic Absorption)

Segment "A" of Figure 2 represents the "normal" wear portion of the curve, while Segment "B" represents the increasing, or "abnormal", wear portion. The point at which the two curves meet is called the join point, which indicates the calculated time prior to detection and the concentration value (ppm) at which normal wear accelerates to abnormal wear. Segment "B" is defined by slope B_1 and y-intercept B_0. Segment "A" is described by slope B_3 and y-intercept B_2.

CHAPTER THREE

RESULTS

3.1 FORMULATION OF DECISION CRITERIA

The decision criteria for each equipment/end item/spectrometer combination considered in this study are presented in the Decision Tables in Appendix B. The tables are designed so that, for a given spectrometer reading for a particular metal, an action recommendation code (per T.O. 42B2-1-9) is indicated. Two basic ground rules were followed in deriving the numerical values in the tables:

- In order to retain only whole-number values, fractional values were usually rounded downward to the next lower whole number; this tends to make the criteria favor a "safe" recommendation.
- In order to provide unambiguous criteria, overlapping of values in more than one code was not allowed.

Whenever possible, the decision criteria for given equipment/end item/spectrometer/wearmetal elements were derived from data analyzed as described in Chapter Two. It is obvious from Table 4, however, that there are many cases for which sufficient data did not exist to permit statistical analysis. In those cases, the existing guidelines set forth in the Safety Supplement, T.O. 42B2-1-10SS-2, 12 December 1973, were used as the basis for deriving decision criteria. The following subsections describe the procedures used for deriving decision criteria based on data, as well as those based on existing guidelines; they also present examples to illustrate the application of those procedures and the resulting tables.

3.1.1 Criteria Derived from Regression Analysis of Data

The graphical plots of Appendix A depict all data analyzed for a given equipment/end item/spectrometer/wearmetal element with the regression-analysis curve fit superimposed. It is from these curve fits that the corresponding numerical values in the Decision Tables in Appendix B were derived. The following factors were considered in the selection of decision criteria for each recommendation code:

- Equipment mission duration and operational environment
- Routine oil-sampling intervals as set forth in T.O. 42B2-1-9 and/or Command policies

- Sufficient time for the SOAP analyst to warn maintenance of a probable impending failure based on the SOAP-identified failure histories considered in this report

The "T" code value was determined as the maximum wearmetal reading at which the unit should be grounded for maintenance; it generally corresponds to the wearmetal-concentration-curve value at the point where the operating hours prior to detection are slightly greater than the time required for one flight or operating cycle.

The lower value of the "K" code range was then selected to provide for verification of developing failure trends, without grounding the equipment, while providing for sufficient reaction time for the analyst to notify the maintenance activity of such trends. The upper "K" value was set at one ppm less than the "T" value.

For equipments that are sampled less frequently than after each flight, a provision was made for tightening the sampling interval when the wearmetal concentration reaches a certain level so that increased surveillance will be provided in the interest of identifying an accelerated rate of wearmetal buildup. Engines normally sampled daily were assigned a "D" code (sample after each flight); engines normally sampled less frequently were assigned an "N" code (sample after each flying day); and other equipments were assigned an "F" code (sample after every five hours of operation). The upper value of the code range for tightened sampling was set at one ppm less than the lower "K" value, while the lower value was generally selected to be slightly lower than the concentration at the regression-analysis "join-point".

The "A" code range was then selected to cover all concentration values falling below the lower value of the next higher code. This range represents the concentration values at which routine sampling can continue at currently prescribed intervals with little likelihood that a SOAP-detectable failure will go undetected.

3.1.2 Criteria Derived from Existing Guidelines

Where sufficient data were not available to permit regression analysis, the "T" code value was made equal to the guideline value as set forth in the Safety Supplement, T.O. 42B2-1-10SS-2, 12 December 1973. The remaining code values were obtained by one of the following methods:

- For specific equipments and spectrometers on which one or more elements had sufficient data to permit criteria derivation as described in Section 3.1.1, an arithmetic ratio between code values for those elements was used to establish corresponding code values for the remaining elements.
- For equipments for which no regression analysis was performed, because of insufficient data, arithmetic ratios for establishing decision criteria were derived by using the corresponding ratios from "similar" equipments for which a regression analysis was performed on at least one element.

3.1.3 Criteria Derived from Observation of Data Plots

There were reasonable samples of data for three equipment/spectrometer/wearmetal combinations, but the data were not amenable to piece-wise regression analysis, because (1) there were large gaps in time between samples or (2) there was no discernible increase in the rate of wearmetal buildup throughout the time prior to failure detection. These three cases are identified by note 3 in Table 4.

Although curve fits could not be obtained for these cases, it appeared from visual observation of the data plots that a "T" recommendation should be made at some concentration value other than the current corresponding guideline value. Accordingly, an appropriate "T" value for each case was selected by considering the factors listed in Section 3.1.1, and the remaining code ranges were determined from arithmetic ratios as described in Section 3.1.2.

3.1.4 Examples of Derivations

The following two examples will illustrate the steps involved in deriving decision criteria, as described in the preceding sections. The first example addresses an equipment that exhibits a rapid rate of approaching failure (steep slope of the "abnormal" wear line described in Section 2.4.3). The second example covers an equipment for which abnormal wear develops more slowly.

3.1.4.1 Example 1

Example 1 consists of the following elements:

- Equipment - TF 41-1
- End Item - A-7
- Spectrometer - A/E35U-3
- Wearmetals Analyzed Statistically - Fe (Figure A-36) and Cu (Figure A-37)
- Routine Sampling Interval - After every flight
- Typical Mission Duration - 1 to 2 hours

Since this equipment is sampled after every flight under existing TAC policy, the codes for a tightened sampling interval do not apply. Action codes "T", "K", and "A" are the only ones for which criteria values need to be derived.

The criteria for Fe will be derived first. As shown on the "abnormal wear" segment of the regression line in Figure A-36, the wearmetal concentration corresponding to approximately two hours prior to detection (maximum typical mission) is 10 ppm. This value is established as the "T" code. In theory, routine sampling could be maintained below this level since samples

are taken after each flight. Because of the wide spread in data shown on Figure A-36, however, it was deemed advisable to make some provision for increased surveillance of a given engine through maintenance inspection before it reaches a point where grounding would be indicated. Accordingly, a "K" value range of 8 to 9 ppm was established, and the "A" range was set at 7 ppm and below.

Similar reasoning was applied in deriving criteria for Cu. From Figure A-37, the wearmetal concentration corresponding to approximately two hours prior to detection is 14 ppm. This was selected as the "T" code value. A "K" value range of 12 to 13 ppm was established, and the "A" range was set at 11 ppm and below.

Criteria for the remaining elements were established by setting the "T" value equal to the present Safety Supplement guidelines, then using the ratios of the Fe code range of "T" to "K" and "T" to "A" for deriving corresponding code ranges.

The resulting decision table is as follows:

		Wearmetal Element					
		Fe	Ag	Al	Cr	Cu	Mg
Code	A	0-7	0-2	0-1	0-2	0-11	0-4
	K	8-9	3	2	3	12-13	5-6
	T	10+	4+	3+	4+	14+	7+

This example points up the need to accumulate additional data and include these data in the analysis base to improve the statistical confidence in the wearmetal-buildup curve. Failures appear to develop rapidly, and the analyst must be able to recognize a developing trend before the equipment condition becomes critical.

3.1.4.2 Example 2

Example 2 consists of the following elements:

- Equipment - T56-7/9
- End Item - C-130
- Spectrometer - A/E35U-3
- Wearmetals Analyzed Statistically - Fe (Figure A-38), Cu (Figure A-39), and Mg (Figure A-40)

- Routine Sampling Interval - Every 25 hours (per T.O. 42B2-1-9); once a day after the first flight (per TAC policy)
- Typical Mission Duration
  - 0 to 5 hours (routine flight)
  - 5 to 6 hours (average flight)
  - 7 to 9 hours (frequent flight)
  - 11 to 13 hours (maximum flight duration)

NOTE: 8 hours was selected as a representative mission time.

This equipment is currently sampled daily after the first flight, according to TAC policy. The routine sampling interval prescribed in T.O. 42B2-1-9, however, is every 25 hours of operation. In order to assure that daily samples are taken when wearmetal concentrations begin to build up above normal levels, it was deemed advisable to establish a provision for tightened sampling in case the TAC policy should be relaxed in the future. Decision criteria need to be derived, therefore, for the "N" code (do not change oil, submit redtagged sample after each flying day), as well as for the "T", "K", and "A" codes.

The criteria for Fe will be derived first. As shown on the regression line in Figure A-38, the wearmetal concentration corresponding to eight hours prior to detection is 30 ppm. This value establishes the "T" code. In order to provide verification of developing failure trends through tightened sampling intervals, an "N" value range of 21 to 24 ppm was set. Likewise, a "K" value range of 25 to 29 ppm was established to supply increased surveillance through maintenance inspection before an engine would have to be grounded. The "A" range was set at 20 ppm and below.

A similar line of reasoning was applied in deriving criteria for Cu and Mg. From Figure A-39, the wearmetal concentration for Cu corresponding to eight hours prior to detection is 12 ppm. A "K" value of 11 ppm and an "N" value of 10 ppm were established; the "A" range was set at 9 ppm and below. From Figure A-40, the Mg concentration value corresponding to eight hours prior to detection is 27.7 ppm. This was rounded downward to 27 ppm as the "T" code value. A "K" value range of 25-26 ppm and an "N" value range of 22-24 ppm were established with the "A" range set at 21 ppm and below.

Criteria for the remaining elements were established by setting the "T" value equal to the Safety Supplement guidelines, then using the ratios of the Fe code values of "T" to "K", "T" to "N", and "T" to "A" for deriving corresponding code values.

The resulting decision table is as follows:

Code	Wearmetal Element: Fe	Ag	Al	Cr	Cu	Mg
A	0-20	0	0-3	0-1	0-9	0-21
N	21-24	1	4	2	10	22-24
K	25-29	2	5-6	3	11	25-26
T	30+	3+	7+	4+	12+	27+

3.2 USE OF DECISION TABLES AND DIAGNOSTIC GUIDANCE

For each equipment considered in this study, Wearmetal Decision Tables and diagnostic guidance were constructed (they are presented in Appendix B). The Wearmetal Decision Tables were prepared as described in Section 3.1. The diagnostic guidance basically represents the amplifying notes, or descriptive material, found in T.O. 42B2-1-10SS-2 of 12 December 1973, with minor alterations to the text based on the results of this study.

3.2.1 Wearmetal Decision Tables

To provide laboratory analysts with more positive guidance for evaluating SOAP results, a set of Wearmetal Decision Tables was developed. Appendix B describes the manner in which these tables are to be used. It should be noted that the procedure for using the tables will automatically result in a request for a redtagged sample before a major maintenance action is recommended; if an excessively high concentration is verified, a maintenance recommendation should then be made.

It is emphasized that the analyst must be continually alert for developing failure trends and rapid increases in wearmetal concentration, even though the actual concentration values fall within the "safe" ranges in the Decision Tables. This is particularly important for equipments that show a tendency to fail rapidly after the first indication that failure is likely, such as the TF41 in the A-7 and the TF30 in the F-111 aircraft.

3.2.2 Diagnostic Guidance

Corresponding to the Wearmetal Decision Tables for each equipment is a diagnostic text. This is designed to assist the SOAP analyst in classifying an oil-wetted component as suspect on the basis of increasing wearmetal trends.

3.2.3 Example of Use

For the TF41-1/A-7 found in Appendix B on page B-32, it is assumed that the following parameters are known:

- Spectrometer: A/E35U-3
- Wearmetal-element concentration values (ppm) from a routine oil sample:

Fe - 7	Cr - 0
Ag - 0	Cu - 13
Al - 0	Mg - 5

From the Wearmetal Decision Table, it can be seen that Fe, Ag, Al, and Cr concentration values fall within the "A" recommendation code -- "Continue routine sampling". However, Cu and Mg concentration values fall in the "K" code range -- "Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded". Under the recommended procedure, the analyst would use the action code that prescribes the most severe action, i.e., "K".

In addition to advising maintenance to inspect for a possible discrepancy, the SOAP laboratory analyst can use the diagnostic guidance to suggest specific areas of investigation. With Cu and Mg considered as major wearmetals in this example, the external gearbox is a likely area of impending failure.

CHAPTER FOUR

CONCLUSIONS AND RECOMMENDATIONS BASED ON STUDY OBSERVATIONS

4.1 LIMITATIONS ON USE OF WEARMETAL DECISION TABLES

For equipments exhibiting high oil consumption or having small oil-tank capacities, wearmetal buildup trends can best be analyzed by graphically plotting element-concentration values (ppm) versus equipment operating hours in addition to using the Wearmetal Decision Tables. Further, studies of wearmetal-production rates, currently in progress by the Aerospace Research Laboratories, should be continued to determine if these rates can be applied to the development of improved decision criteria.

4.2 OIL CHANGES

Whenever wearmetal-concentration values increase beyond the "A" code value range as defined in the Decision Tables, it is recommended that the equipment oil not be changed. Changing oil after wearmetal trends become evident will only contribute to reducing the effectiveness of trend analysis in identifying incipient failures.

4.3 RECOMMENDATION-CODE REDUCTION

The number of laboratory recommendation codes given in T.O. 42B2-1-9 could be reduced to those cited in the Decision Tables. The codes listed therein will result in more consistent requests for maintenance action without impairing the effectiveness of the oil analysis program.

4.4 PERIODIC EVALUATION

All SOAP data (for the equipments considered in this study) accumulated following the publication of this report should be reviewed, evaluated, and analyzed periodically. Where the data permit, new criteria should be prepared or existing criteria updated.

4.5 DEVELOPMENT OF DECISION CRITERIA FOR ALL AIR FORCE SOAP-MONITORED EQUIPMENTS

By use of the methodology and format set forth in this report, decision criteria for the balance of USAF-SOAP-monitored equipments should be developed and incorporated in the revised Technical Manual.

4.6 INDEXED TECHNICAL MANUAL

The revised Technical Manual for the SOAP evaluation criteria should be indexed by equipment and end item for easy reference (see Appendix B, page B-3).

4.7 MAINTENANCE FEEDBACK

During the course of this study, maintenance actions were observed to be inaccurately reported, or unreported, for many SOAP-identified discrepancies. Hence, the procedure for reporting all SOAP-related maintenance actions to the laboratory should be improved to provide greater accuracy.

4.8 EDITING OF SOAP UNIT FAILURE HISTORIES

SOAP-identified maintenance actions are currently recorded in the San Antonio ALC Computer Data Bank. However, recurring anomalies were observed in the review of these data. For example, wearmetal-concentration values were frequently observed to have large, unexplainable variations from one reading to the next. Similarly, many equipment histories exhibited sizable gaps in operating hours since overhaul or operating hours since oil change, some exceeding 200 hours. Some histories reviewed had no indication of operating hours. Thus a procedure should be initiated for the editing of these data to provide accuracy, uniformity, and clarity to the SOAP Unit Failure Histories as recorded in the Data Bank.

4.9 F-101/F-102 DECISION CRITERIA

Because differing wearmetal-buildup trends have been observed, it is suggested that separate decision criteria be considered for F-101/F-102 powerplants when additional data become available.

4.10 "QUICK LOOK" OIL ANALYSIS

Consideration should be given to the use of a "quick look" oil analysis technique to reduce laboratory and organizational maintenance workloads by decreasing the number of samples processed. Such a technique, using the Mobil Fotoscope, is currently being employed by National Airlines (see Section 2.1).

APPENDIX A

EQUIPMENT DATA-ANALYSIS PLOTS AND TABULATION OF EQUIPMENT MALFUNCTIONS CONSIDERED IN THIS STUDY

The figures in this appendix represent the available SOAP data used in this study with the "piece-wise" regression-analysis curve fit superimposed. Wearmetal-concentration values in parts per million (ppm) are plotted against equipment operating hours prior to detection of an incipient failure for each equipment/end item/spectrometer/wearmetal element. (A table of contents is presented on page A-3 as a cross-reference to the figures contained in this appendix.)

Several data plots have numbers in parentheses identifying specific data points. These digits specify the number of equipment histories having conincident data values.

On the basis of the "piece-wise" regression analysis results found in Chapter Two, Table 5, each set of data is described by a segmented, linear curve fit.

The tabulation appearing below each figure in this appendix lists the SOAP-identified malfunctions considered for each equipment/end item/spectrometer/wearmetal element. The following are explanations of the column headings.

- Equipment S/N - The last four digits of each equipment serial number (S/N) are listed in numerically ascending order.
- Date of Detection - This date identifies the time at which the SOAP analyst detected a possible discrepancy and requested maintenance inspection or removal from service of the equipment in question. The Date of Detection is tabulated in the format used in the SOAP Data Bank, with the first two digits representing the year; the next two digits, the month; and the last two digits, the day. For selected histories recorded in the RCS: K-30 reports, only the month and year were reported. In such cases, the day will be designated by (00) in this appendix.

- Reported Malfunction - The Reported Malfunction is that discrepancy reported by maintenance as having been detected by SOAP. If the component malfunction was not recorded for a SOAP unit failure history, "Unknown" will be cited under "Reported Malfunction", with the source of the data given in parentheses.

The spectrometric instruments considered in this appendix are identified as follows:

- Baird-Atomic A/E 35U-1 (Emission)
- Baird-Atomic A/E 35U-3 (Emission)
- Perkin-Elmer 303/305 (Atomic Absorption)

The wearmetal elements described in this appendix are identified as follows:

Al - Aluminum

Cr - Chromium

Cu - Copper

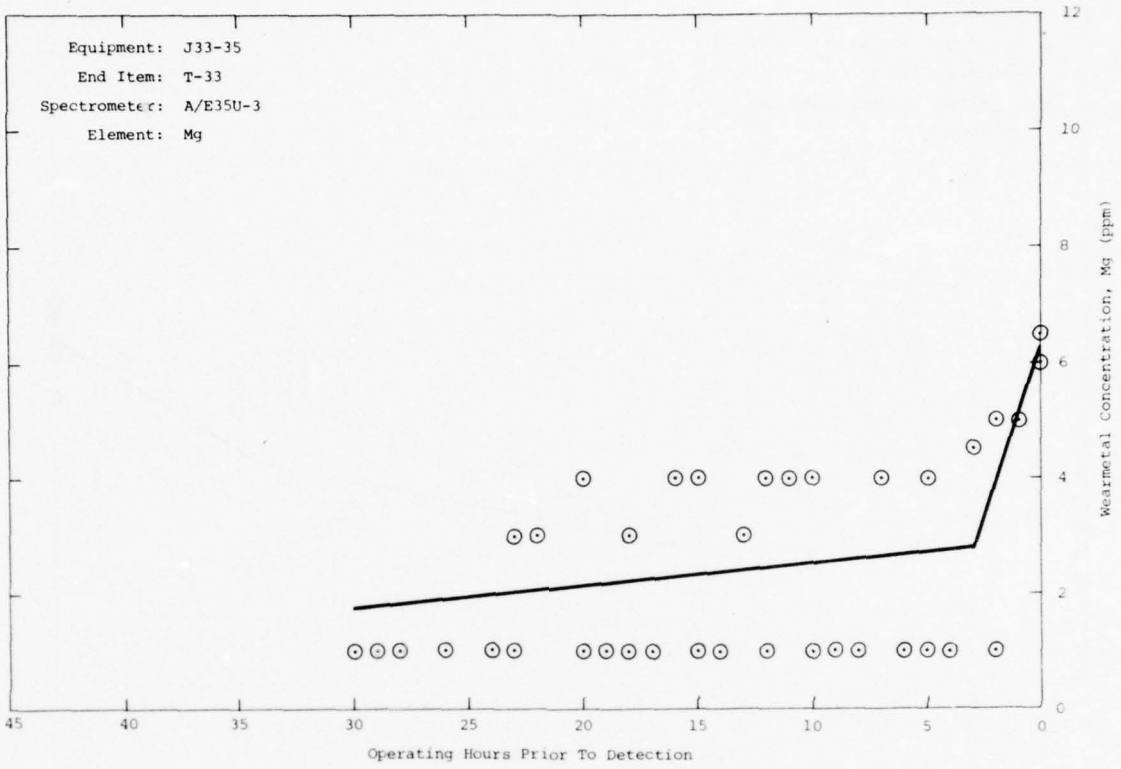
Fe - Iron

Mg - Magnesium

INDEX OF EQUIPMENTS AND WEARMETALS				
Equipment	End Item	Spectrometer	Element	Figure Number
J33-35	T-33	A/E35U-3	Mg	A-1
		Atomic Absorption	Fe	A-2
		Atomic Absorption	Mg	A-3
J57-13/23	F-101/F-102	A/E35U-3	Fe	A-4
J57-13/23/55	F-101/F-102	A/E35U-3	Cu	A-5
J57-19/43/59	B-52/C-135	A/E35U-3	Fe	A-6
		A/E35U-3	Mg	A-7
		Atomic Absorption	Fe	A-8
J57-21/23	F-100/F-102	Atomic Absorption	Fe	A-9
J60-3	T-39	Atomic Absorption	Fe	A-10
		Atomic Absorption	Mg	A-11
J69-25	T-37	A/E35U-3	Fe	A-12
		A/E35U-3	Cr	A-13
		A/E35U-3	Cu	A-14
		Atomic Absorption	Fe	A-15
J75-17/19	F-106/F-105	A/E35U-3	Fe	A-16
		Atomic Absorption	Fe	A-17
		Atomic Absorption	Al	A-18
J79-11	F-104	A/E35U-3	Fe	A-19
		A/E35U-3	Cu	A-20
J79-15/17	F-4	A/E35U-1	Fe	A-21
		A/E35U-3	Fe	A-22
		A/E35U-3	Cu	A-23
		A/E35U-3	Mg	A-24
		Atomic Absorption	Fe	A-25
		Atomic Absorption	Cu	A-26

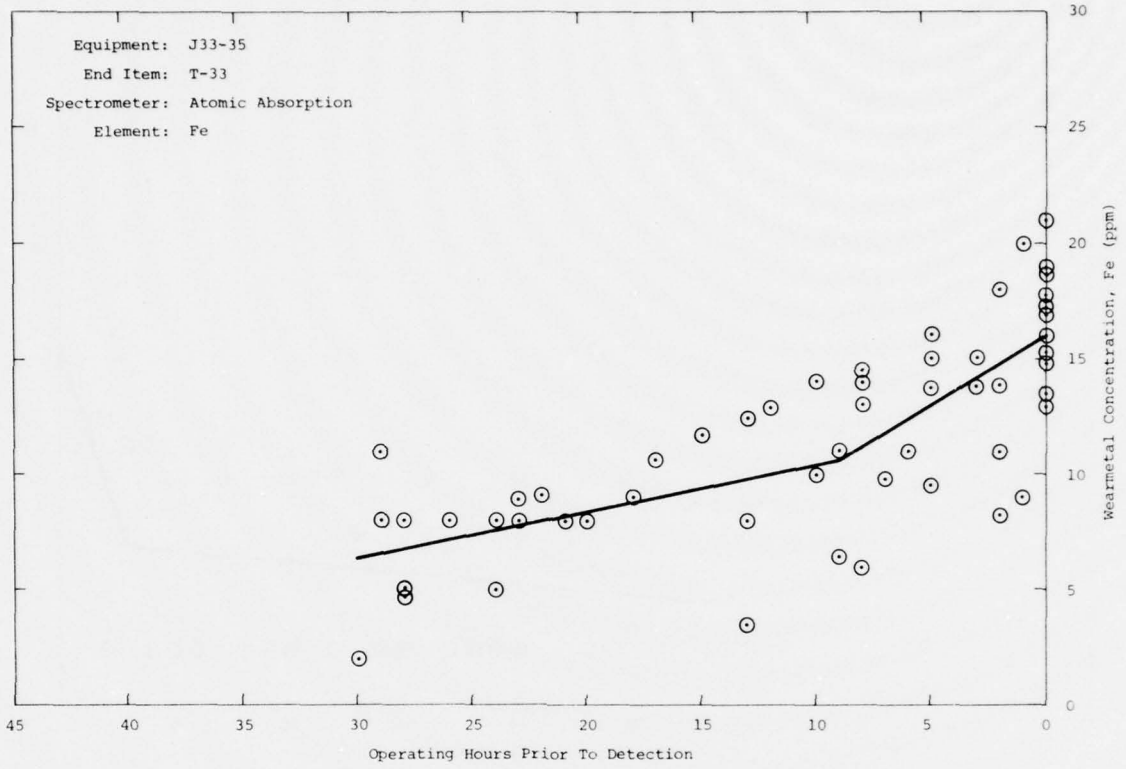
(continued)

INDEX OF EQUIPMENT AND WEARMETALS (continued)				
Equipment	End Item	Spectrometer	Element	Figure Number
J85-5/17	T-38/A-37	A/E35U-3	Fe	A-27
		A/E35U-3	Cu	A-28
		A/E35U-3	Mg	A-29
		Atomic Absorption	Fe	A-30
		Atomic Absorption	Mg	A-31
TF30-All Series	F-111/FB-111	A/E35U-1	Fe	A-32
		A/E35U-3	Fe	A-33
		Atomic Absorption	Fe	A-34
TF33-All Series	B-52/C-135/ C-141	A/E35U-3	Fe	A-35
TF41-1	A-7	A/E35U-3	Fe	A-36
		A/E35U-3	Cu	A-37
T56-7/9	C-130	A/E35U-3	Fe	A-38
		A/E35U-3	Cu	A-39
		A/E35U-3	Mg	A-40
		Atomic Absorption	Fe	A-41
		Atomic Absorption	Cu	A-42
		Atomic Absorption	Mg	A-43
R2800-All Series	C-118/C-131/ T-29	A/E35U-3	Fe	A-44
		A/E35U-3	Al	A-45
GTCP85-106	C-141(APU)	A/E35U-3	Fe	A-46
GTCP85-397	M32A-60	A/E35U-3	Fe	A-47
		Atomic Absorption	Fe	A-48
		Atomic Absorption	Cu	A-49



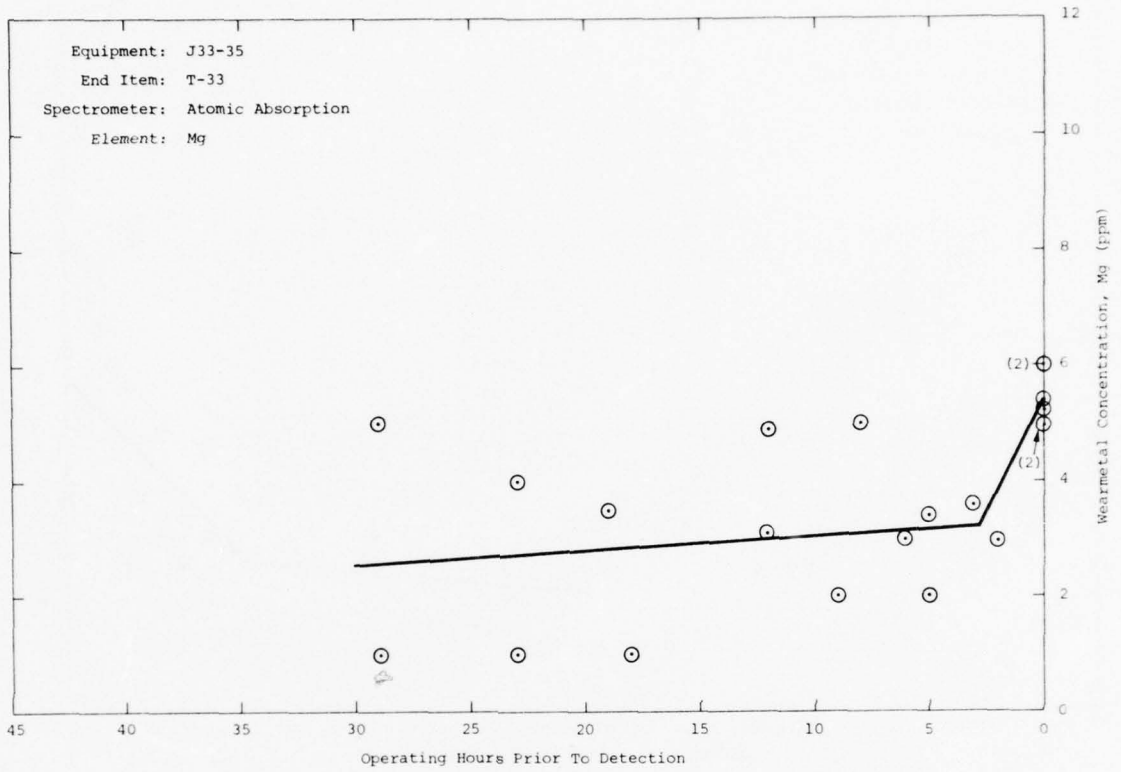
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
7313	720809	Auxiliary Drives and Accessories, Bearing			
7346	720620	Oil Pump, Compressor Section			

Figure A-1.



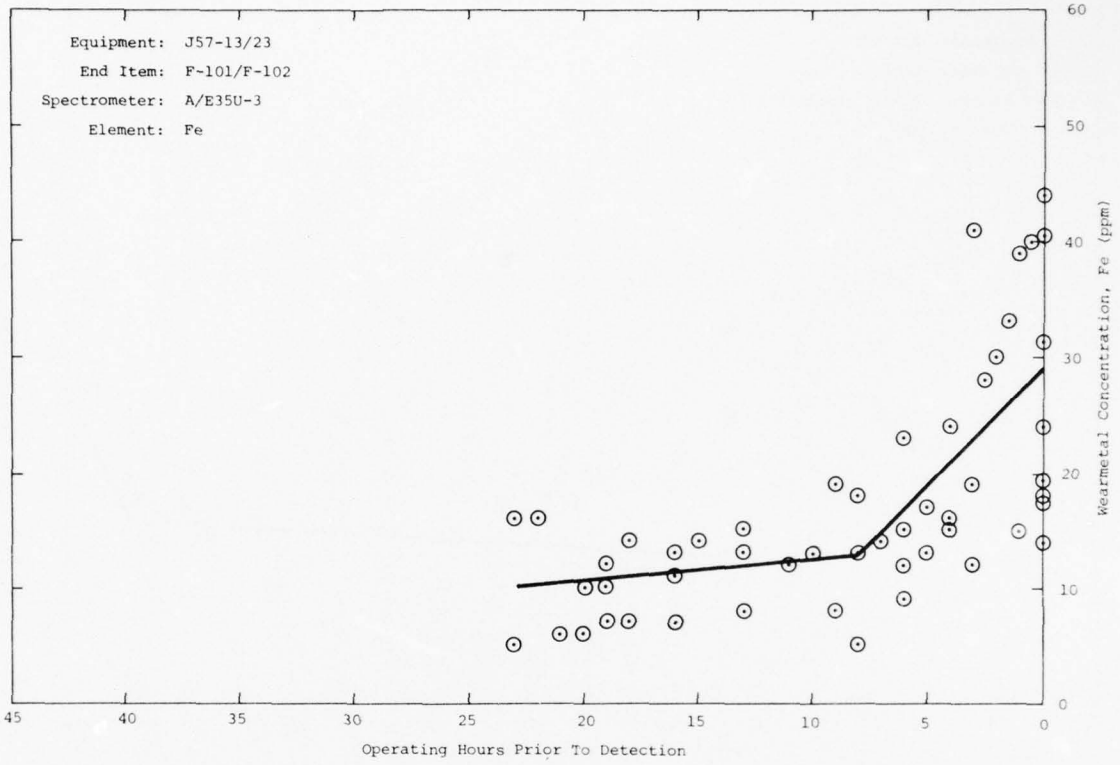
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0815	691009	Number 3 Main Bearing			
2336	690416	Number 2 and Number 4 Main Bearings			
3070	730913	Auxiliary Drives and Accessories			
4675	720216	Number 3 Main Bearing			
5160	730815	Gears, Reduction Gearbox			
6253	690717	Auxiliary Drives and Accessories, Bearings			
6253	690915	Main Bearing(s)			
6568	700206	Number 3 and Number 4 Main Bearings			
6568	730410	Main Bearing(s)			
6850	730723	Gears, Reduction Gearbox			
7451	730220	Gear, Air Inlet Section			

Figure A-2.



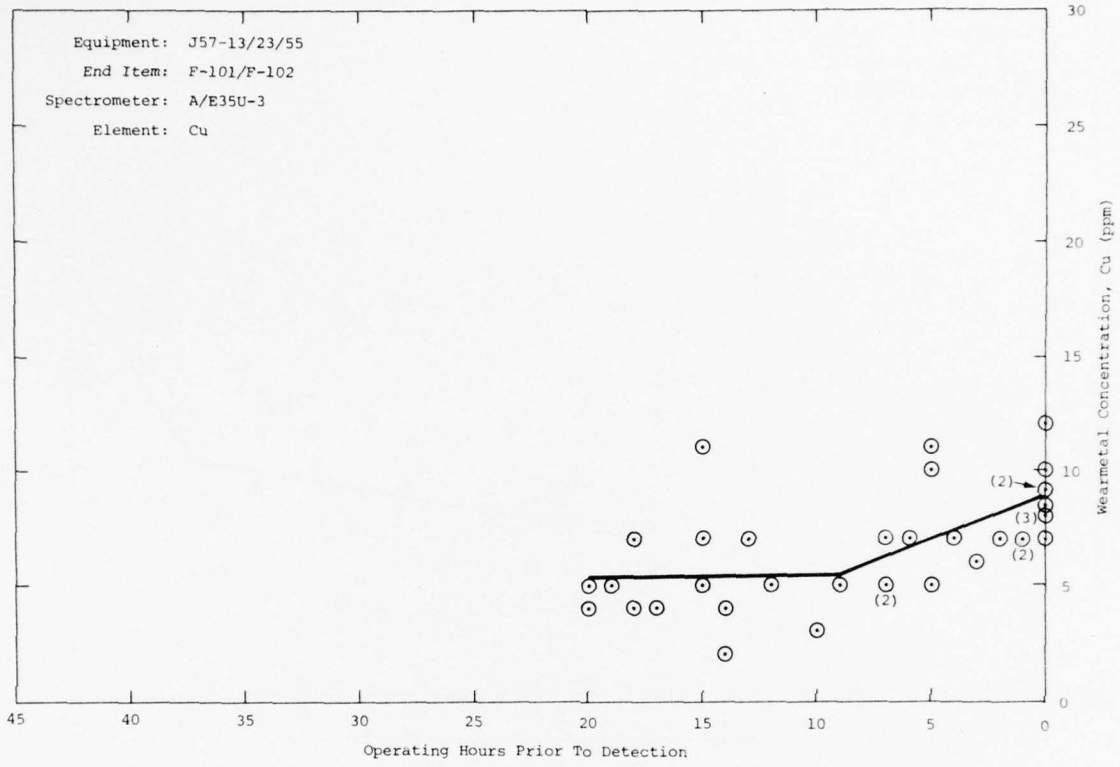
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0909	690927	Oil Pump, Air Inlet Section			
1298	690900	Oil Pump, Air Inlet Section			
1750	720229	Oil Pump, Air Inlet Section			
4675	720216	Number 3 Main Bearing			
6146	730222	Shaft Assembly, Air Inlet Section			
7451	730220	Gear, Air Inlet Section			

Figure A-3.



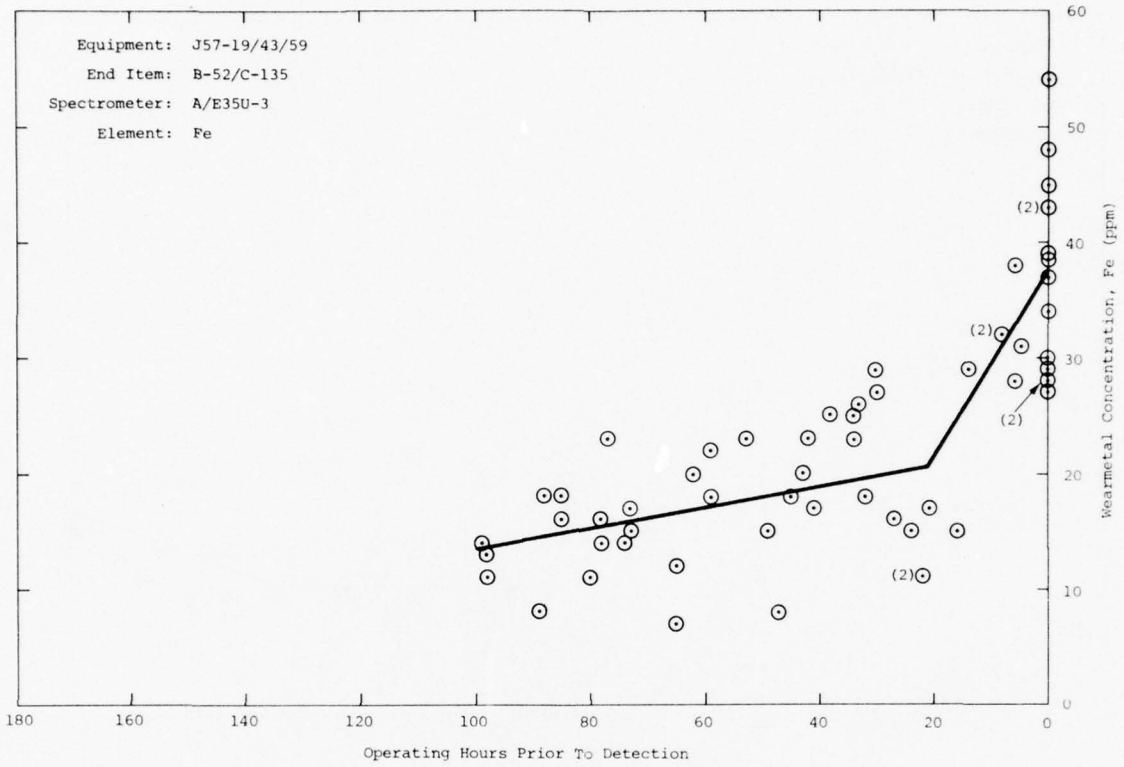
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
5509	721211	Gearbox, Front, Inlet			
5509	730104	Number 3 Main Bearing; Constant Speed Drive; Auxiliary Drives and Accessories			
7242	730303	Gearbox, Front, Inlet			
7564	720920	Constant Speed Drive			
7672	720403	Main Bearing(s)			
8055	720317	Auxiliary Drives and Accessories			
8449	720515	Number 6 Main Bearing			
9214	731203	Number 1 Main Bearing			

Figure A-4.



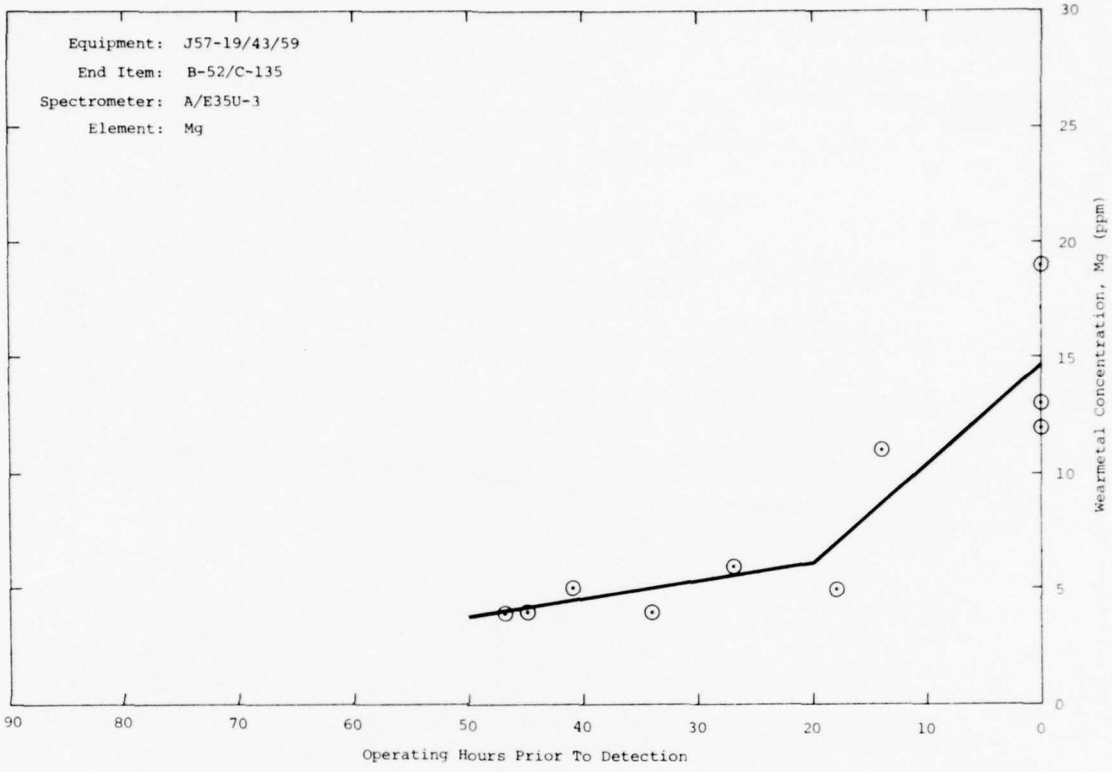
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0037	730221	Number 4 Main Housing			
1622	721221	Unknown (SOAP Data Bank)			
2048	730414	Oil Pump, Reduction Gearbox			
5837	730516	Auxiliary Drives and Accessories, Bearing			
6240	720403	Main Bearing(s)			
7648	730607	Constant Speed Drive			
7672	720403	Main Bearing(s)			
8449	720515	Number 6 Main Bearing			
9202	720421	Main Bearing(s)			

Figure A-5.



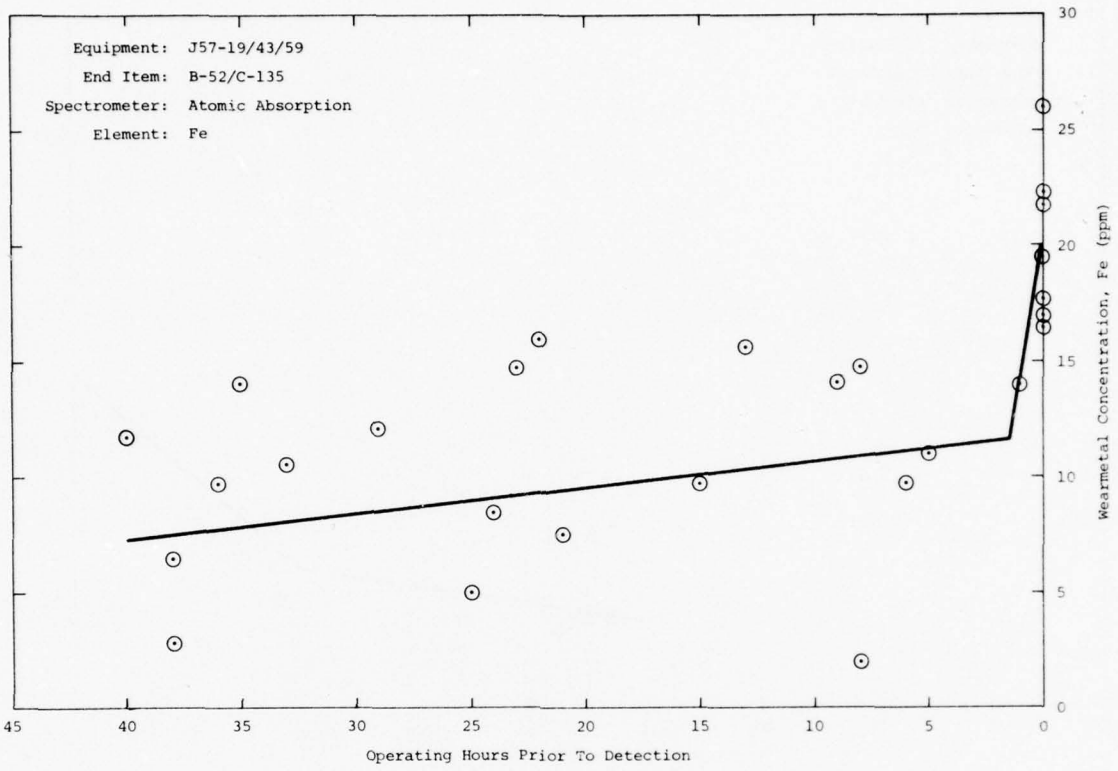
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0522	730620	Number 4 1/2 Main Bearing			
1048	730917	Number 6 Main Bearing			
1390	730501	Unknown (SOAP Data Bank)			
2791	730216	Auxiliary Drives and Accessories, Bearing			
3097	730314	Number 1 Main Bearing			
4000	730122	Auxiliary Drives and Accessories, Bearing			
4249	730802	Number 4 Main Bearing			
4421	731109	Oil Pump, Compressor Section			
6677	730214	Main Bearing(s)			
7732	730130	Number 4 1/2 Main Bearing			
7866	720911	Main Bearing(s)			
8938	731011	Number 6 Main Bearing			
9169	730907	Oil Cooler			
9999	731109	Number 4 Main Bearing			

Figure A-6.



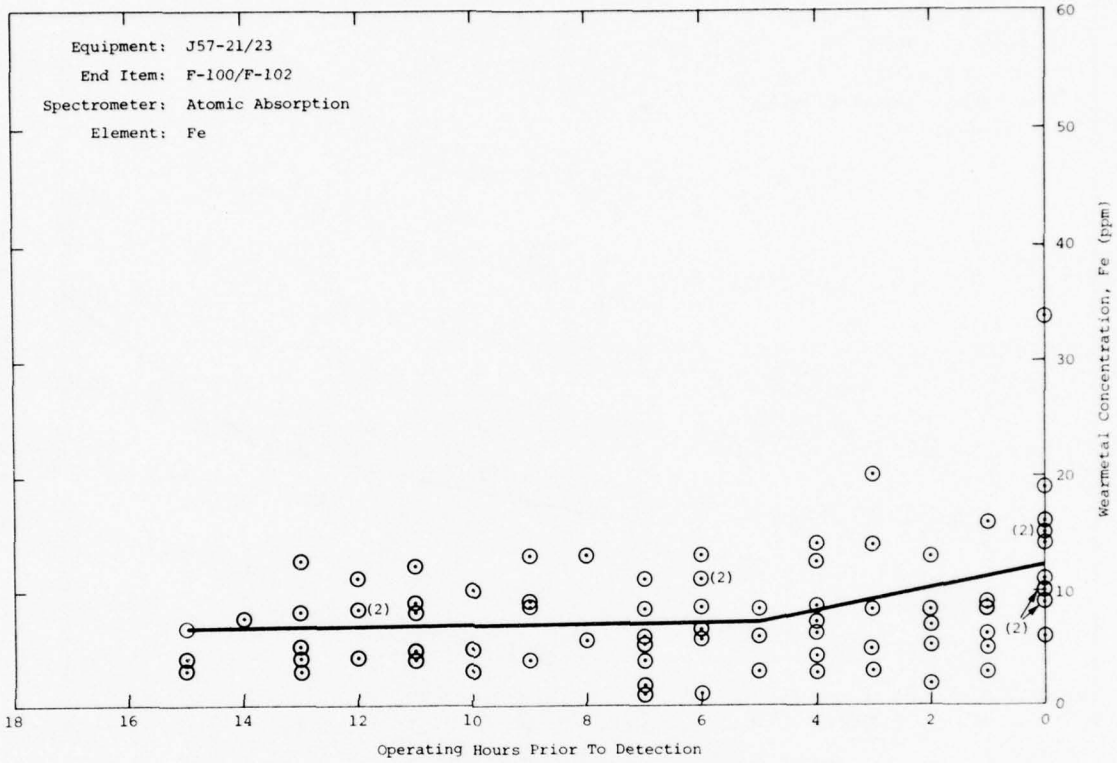
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
2711	730426	Gears, Reduction Gearbox			
3936	730315	Auxiliary Drives and Accessories			
4000	730122	Auxiliary Drives and Accessories, Bearing			

Figure A-7.



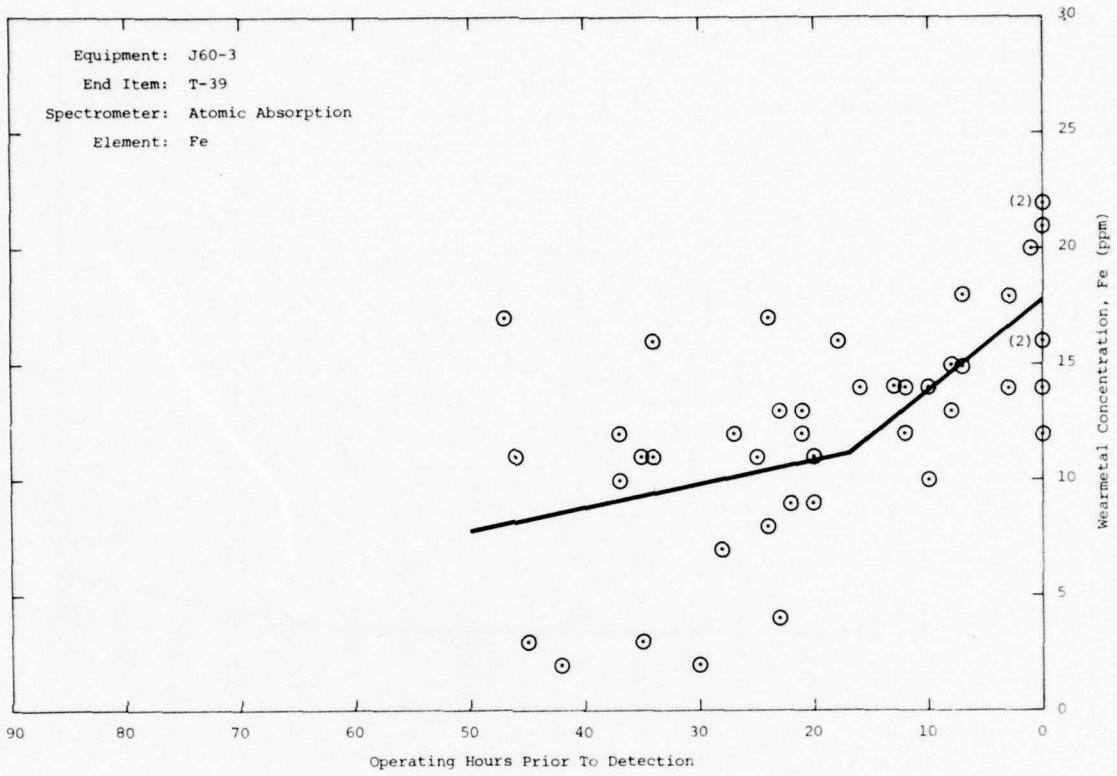
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0532	730131	Number 4 Main Bearing			
0871	690900	Unknown (K-30 Report)			
2875	710518	Auxiliary Drives and Accessories, Bearing			
3720	690800	Number 5 Carbon Seal Plate			
8019	710901	Spacer, Bearing, Turbine Section			
8615	711015	Number 1 Main Bearing			
9539	711110	Number 4 Main Bearing			

Figure A-8.



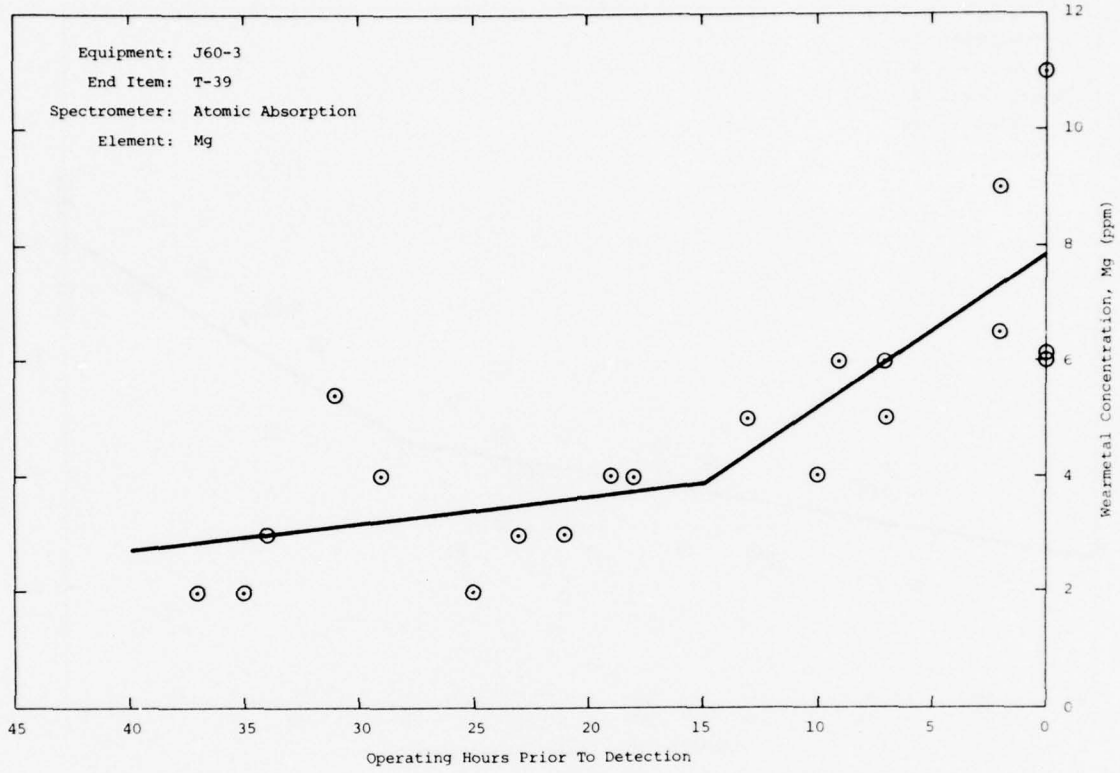
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
2835	720420	Bearing, Accessory Drive, Air Inlet Section			
4830	710921	Auxiliary Drives and Accessories			
4949	730618	Number 5 Main Bearing			
5336	710514	Number 5 Main Bearing			
5998	690804	Number 5 Main Bearing; Number 3 Carbon Seal Plate			
6383	710429	Number 6 Carbon Seal Plates			
6759	731118	Constant Speed Drive			
7423	691217	Number 4 Main Bearing			
7769	730606	Number 5 Main Bearing			
7939	730503	Number 5 Main Bearing			
8055	730111	Constant Speed Drive			
8562	730103	Number 4 Main Bearing			

Figure A-9.



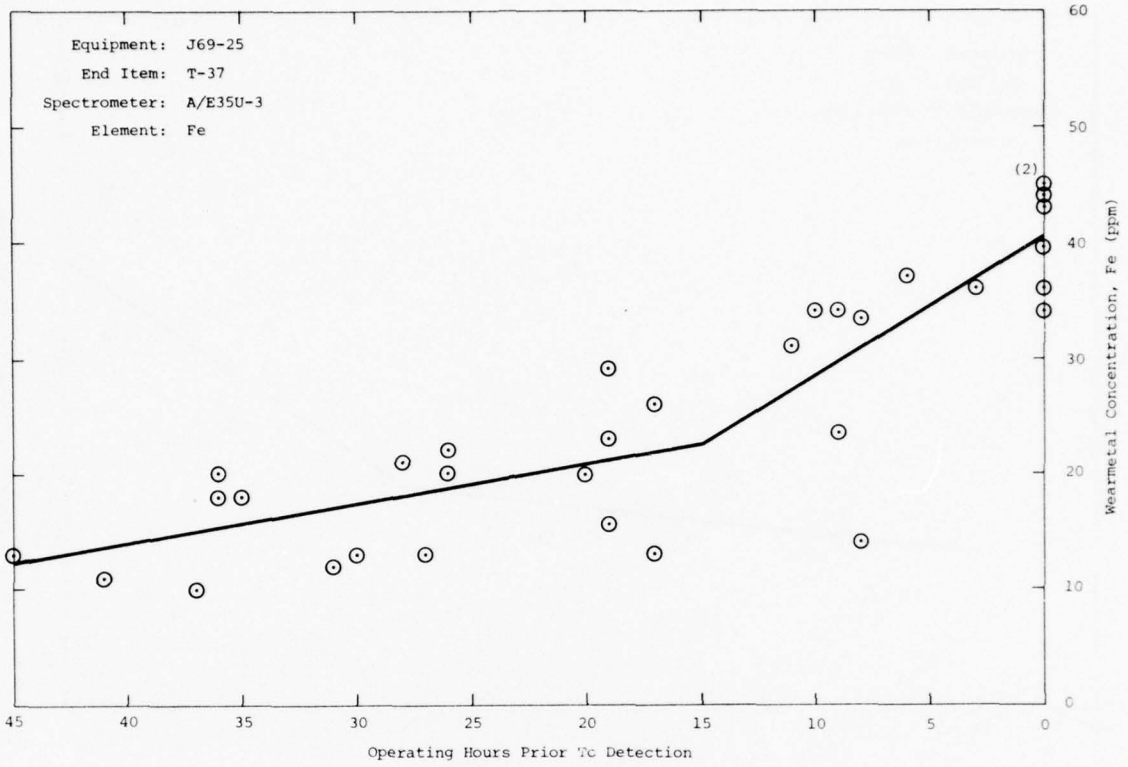
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
6906	730415	Oil Pump, Reduction Gearbox			
6999	731019	Unknown (SOAP Data Bank)			
7095	730319	Reduction Gearbox			
7374	730326	Number 1 Main Bearing			
7374	730618	Number 1 and Number 3 Main Bearings			
7389	730421	Oil Pump, Air Inlet Section			
7389	730618	Number 1 Main Bearing			

Figure A-10.



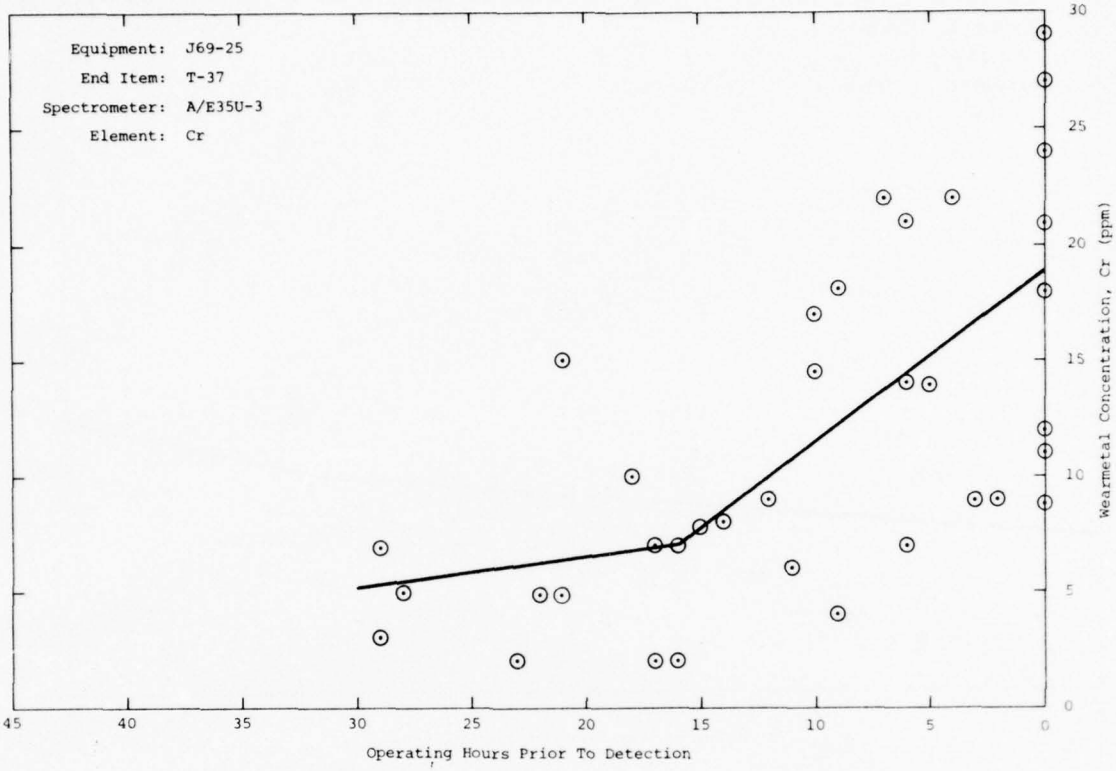
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
6989	730313	Gearbox, Rear, Bearing			
7095	730319	Reduction Gearbox			
7360	720613	Auxiliary Drives and Accessories			

Figure A-11.



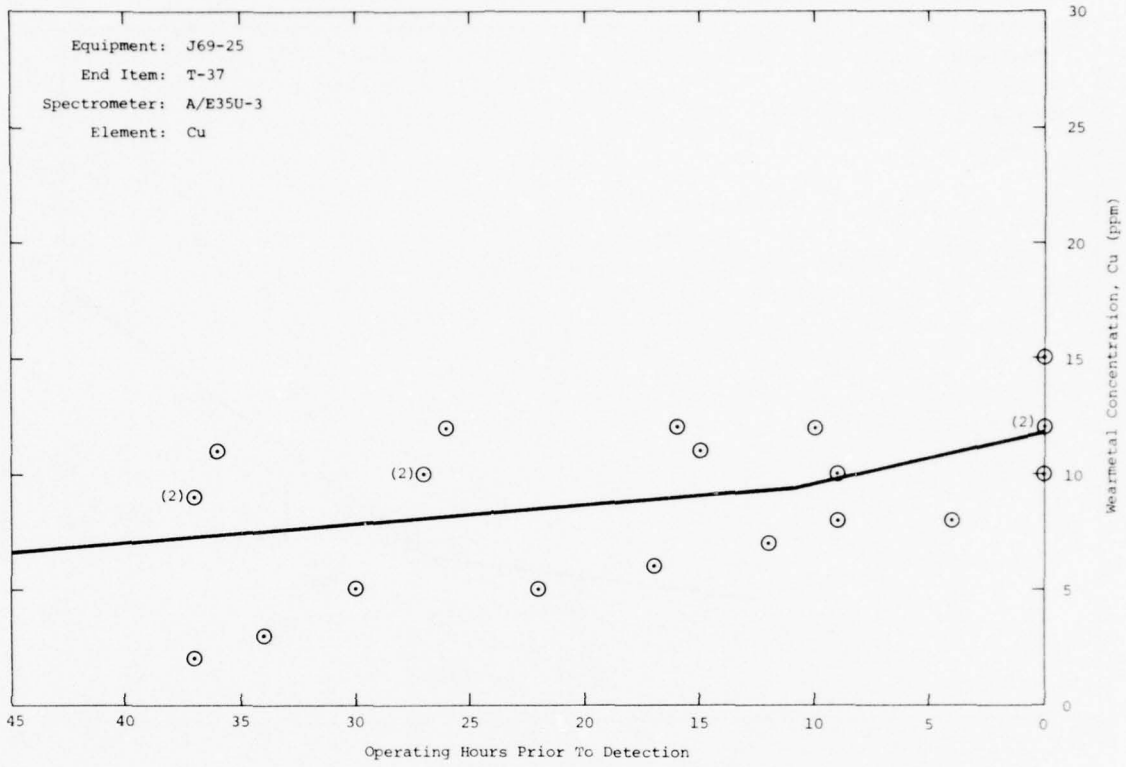
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0992	720918	Number 1 Main Bearing			
0992	721016	Gearbox, Front, Inlet			
1079	730322	Bearing, Accessory Drive, Air Inlet Section			
1134	730109	Number 2 Main Bearing Housing			
1286	720725	Number 3 Main Bearing			
1582	730305	Number 2 Main Bearing; Oil Pump, Compressor Section			
1998	720228	Auxiliary Drives and Accessories, Bearing			

Figure A-12.



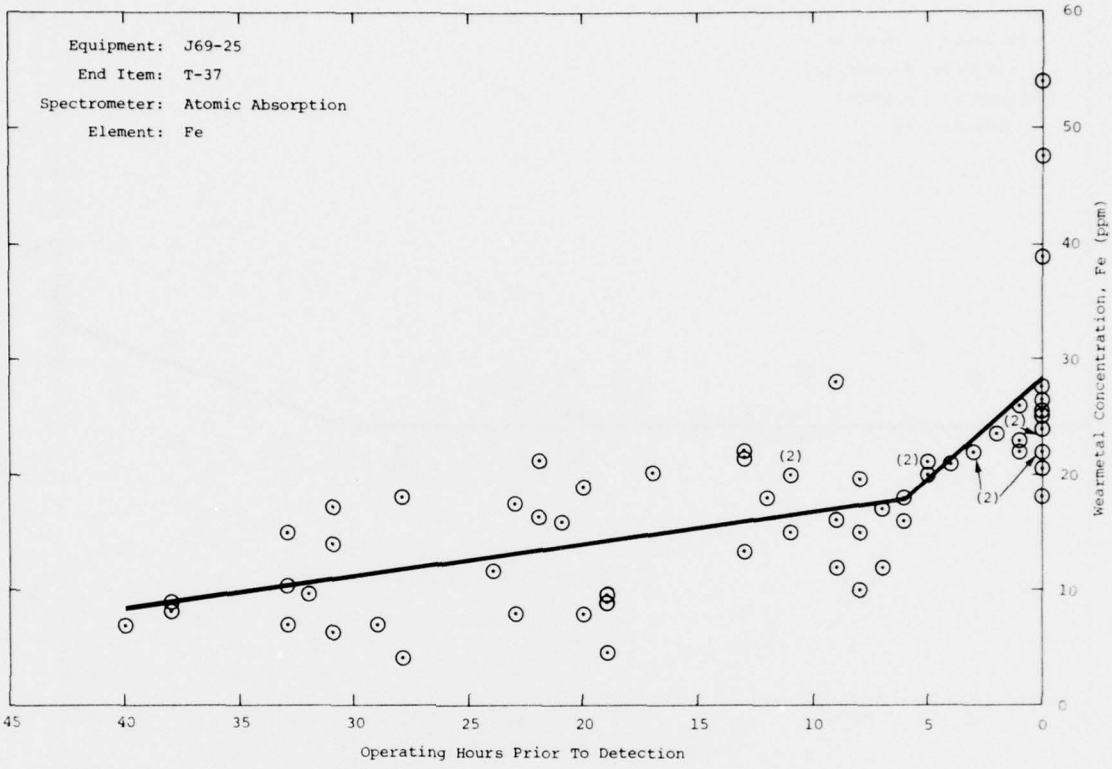
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0266	721012	Auxiliary Drives and Accessories, Bearing			
0654	730606	Oil Pump, Compressor Section			
1123	720901	Oil Pump, Compressor Section			
1393	730104	Oil Pump, Air Inlet Section			
1578	730313	Oil Pump, Air Inlet Section			
1788	720626	Oil Pump, Compressor Section			
1788	730117	Oil Pump, Compressor Section			
1799	720815	Oil Pump, Compressor Section			

Figure A-13.



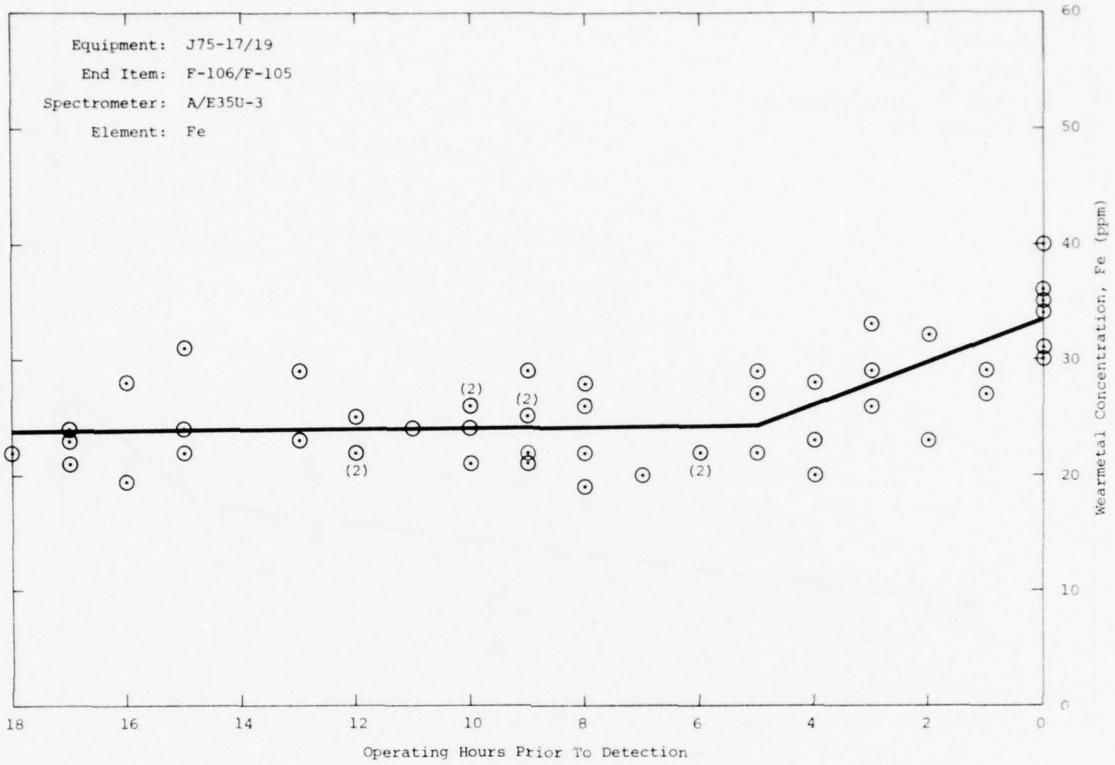
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
1079	730322	Bearing, Accessory Drive, Air Inlet Section			
1320	720426	Auxiliary Drives and Accessories, Bearing			
1398	721026	Oil Pump, Compressor Section			
1407	730711	Shaft Assembly, Air Inlet Section			

Figure A-14.



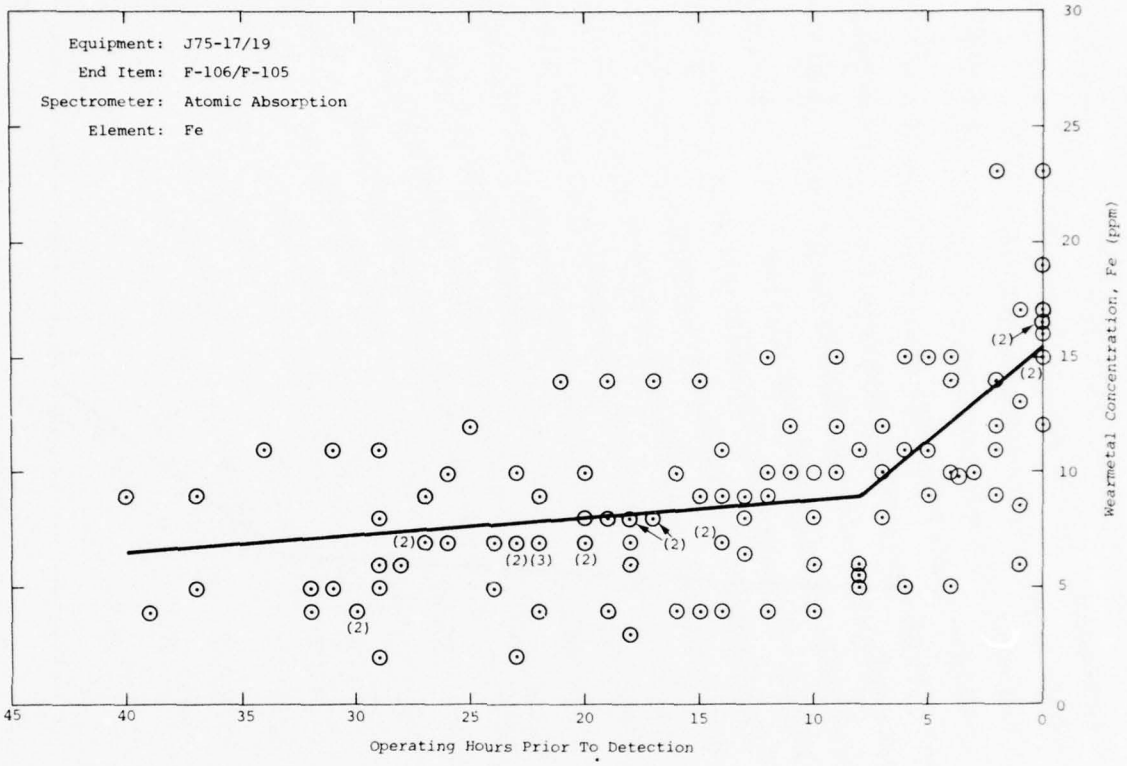
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0157	730918	Bearing, Accessory Drive, Air Inlet Section			
0315	730517	Number 1 Main Bearing			
0410	730207	Shaft Gear, Air Inlet Section			
1157	730530	Number 2 Main Bearing			
1255	730720	Bearing, Accessory Drive, Air Inlet Section			
1306	710519	Gear, Compressor Section			
1335	710429	Bearing, Accessory Drive, Air Inlet Section			
1361	730327	Gearbox, Front, Inlet			
1542	711027	Auxiliary Drives and Accessories			
1725	710907	Number 3 Main Bearing			
1756	701116	Auxiliary Drives and Accessories			
1842	710526	Gearbox, Front, Inlet			
2028	710902	Bearing, Accessory Drive, Air Inlet Section			

Figure A-15.



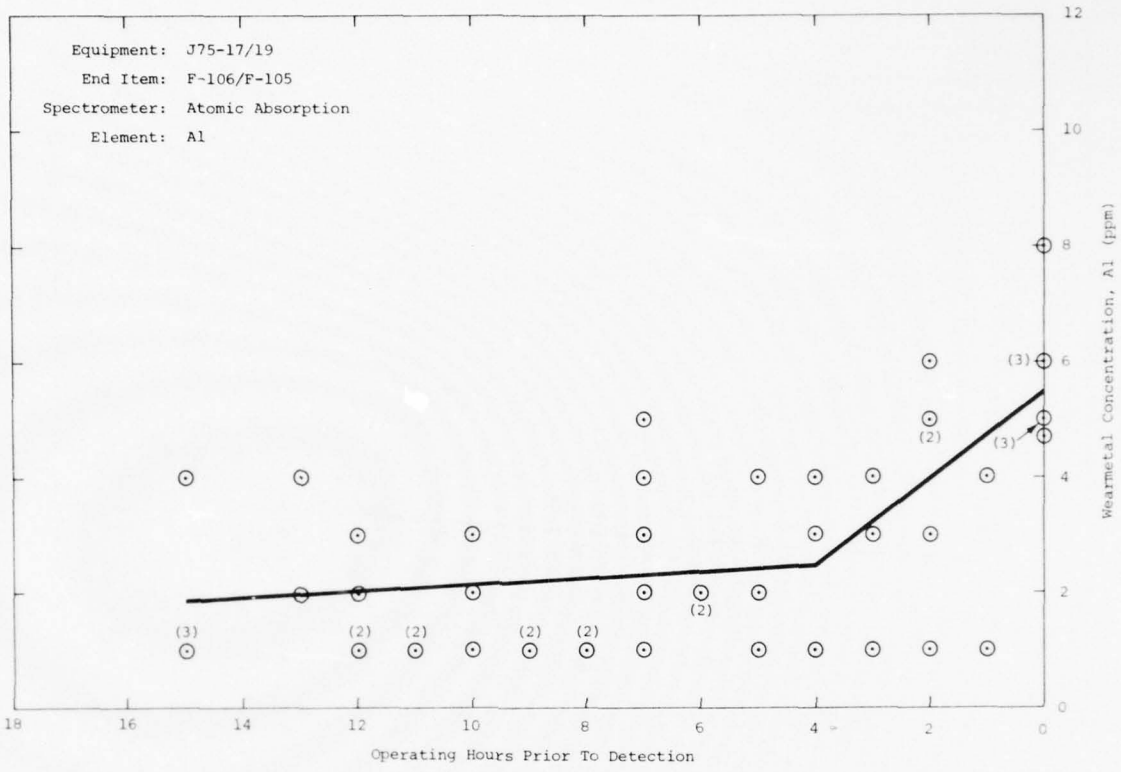
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0476	730411	Number 3 Main Bearing			
0491	730413	Main Bearing(s)			
1043	720829	Oil Pump, Turbine Section			
1628	721113	Number 4 Main Bearing			
2112	730608	Number 5 Main Bearing			
2465	730517	Number 5 Main Bearing			

Figure A-16.



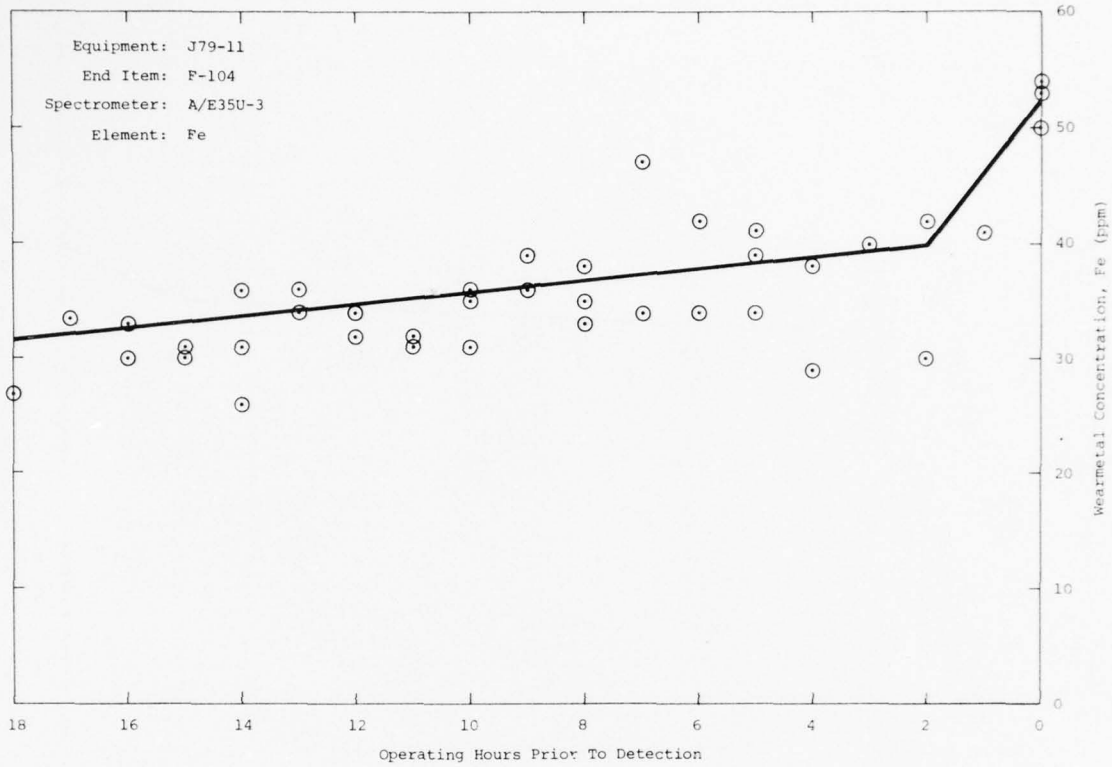
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0117	730921	Number 5 Main Bearing			
0249	730913	Spacer, Bearing Seal, Compressor Section			
0407	720512	Auxiliary Drives and Accessories			
0434	720405	Number 3 Main Bearing Housing			
0434	721212	Number 5 Main Bearing			
0441	730417	Number 5 Main Bearing			
0692	720901	Number 3 Main Bearing Housing			
1029	711029	Number 5 Main Bearing			
1321	730305	Number 5 Main Bearing			

Figure A-17.



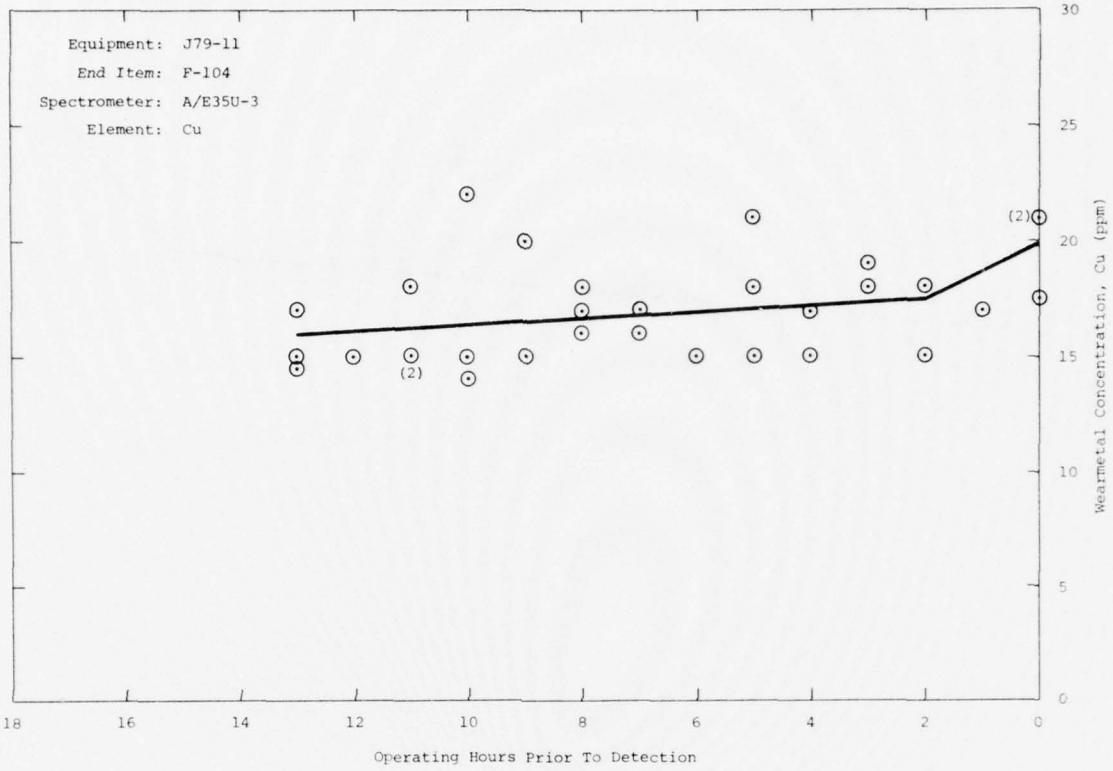
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0080	721104	Oil Pump, Compressor Section			
0080	730208	Oil Pump, Compressor Section			
0104	730519	Oil Pump, Air Inlet Section			
0245	720822	Propeller Shaft, Reduction Gearbox			
0607	721230	Oil Pump, Compressor Section			
0677	730706	Oil Pump, Compressor Section			
1271	730329	Oil Pump, Compressor Section			
1607	721103	Oil Pump, Compressor Section			

Figure A-18.



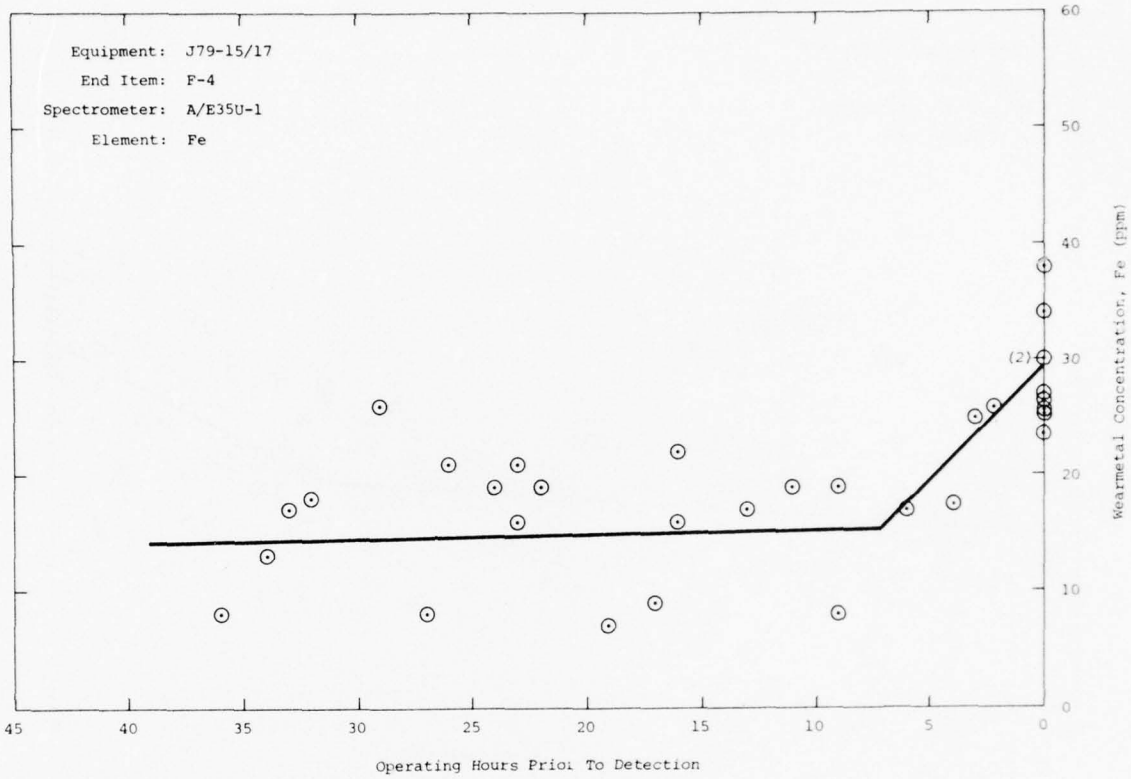
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
1150	730919	Afterburner Nozzle Pump			
1239	730514	Oil Pump, Compressor Section			
3303	730815	Oil Pump, Compressor Section			

Figure A-19.



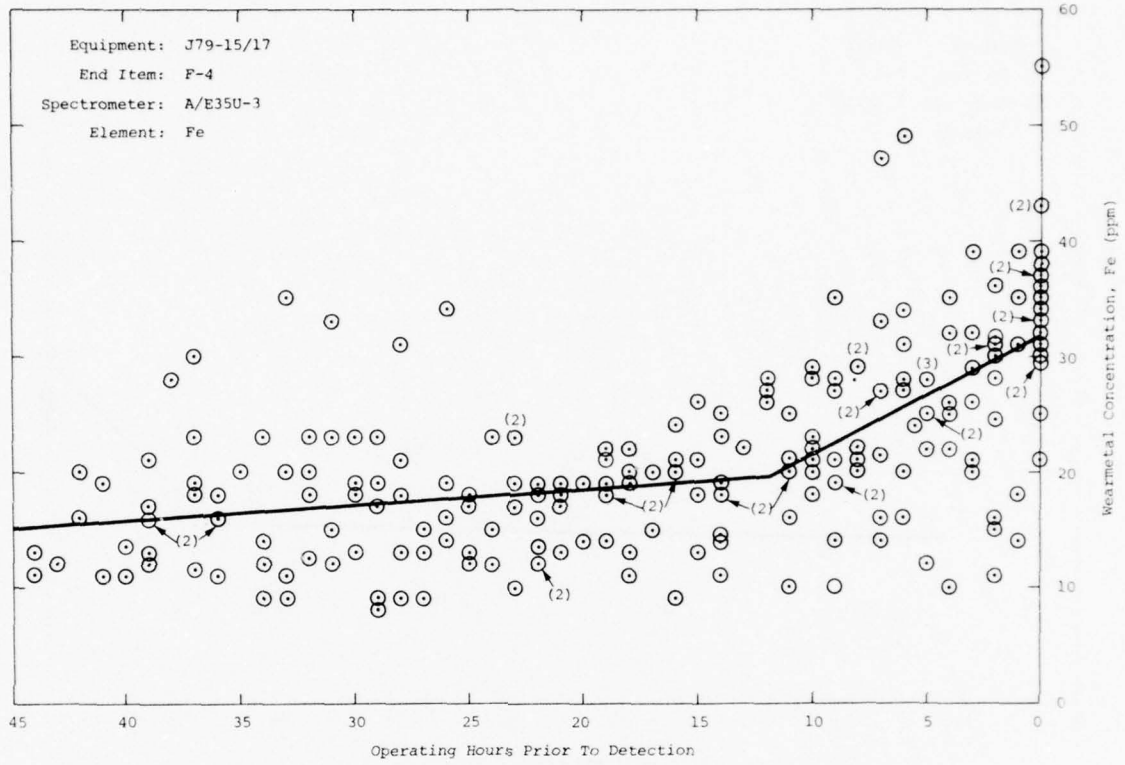
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
1239	730514	Oil Pump, Compressor Section			
1676	730815	Afterburner Nozzle Pump			
3303	730815	Oil Pump, Compressor Section			

Figure A-20.



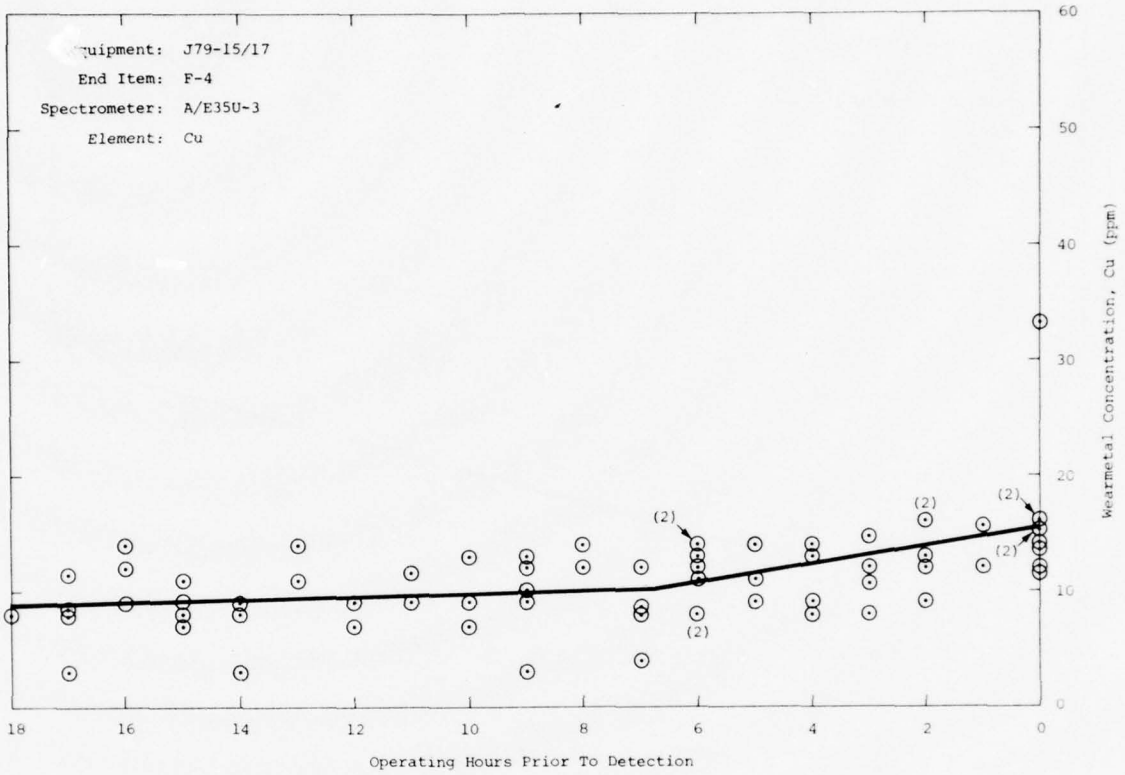
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0294	710511	Gearbox, Front, Inlet			
0430	730716	Auxiliary Drives and Accessories			
0682	720224	Gearbox, Front, Inlet			
0767	720623	Oil Pump, Turbine Section			
3019	711006	Gearbox, Front, Inlet			
4489	711018	Gearbox, Front, Inlet			
8116	730108	Constant Speed Drive			
8806	730421	Constant Speed Drive			
9300	730117	Gearbox, Front, Inlet			

Figure A-21.



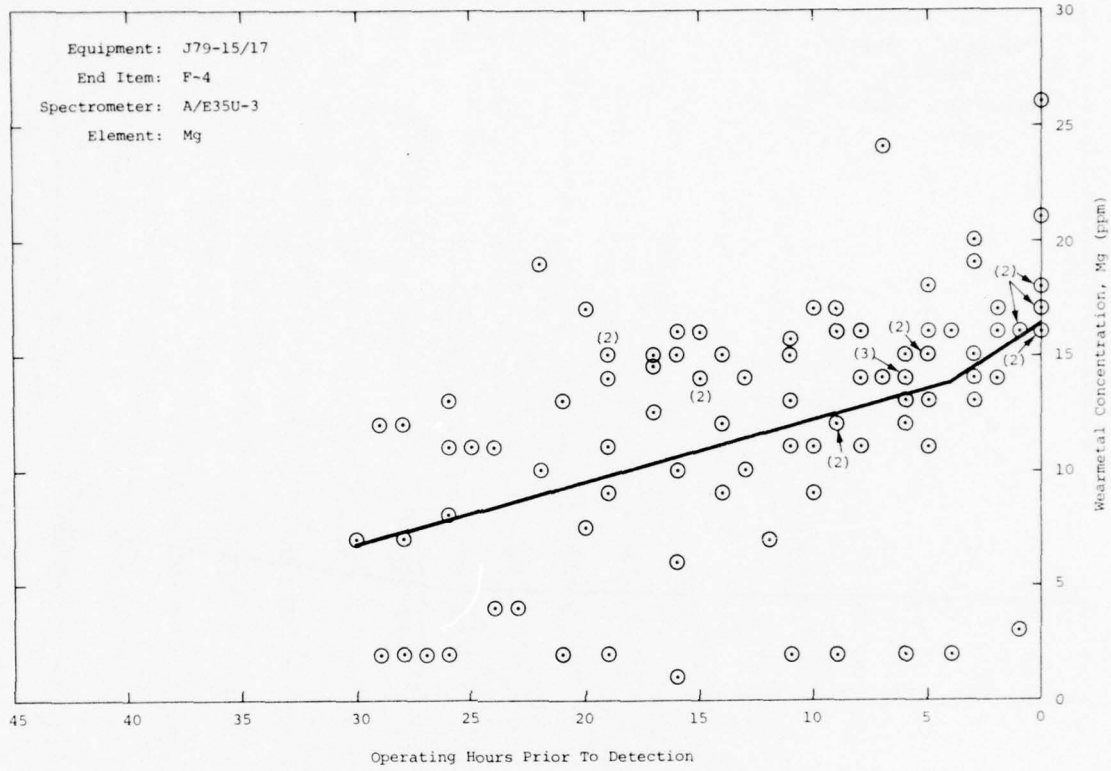
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0048	730510	Constant Speed Drive			
0139	730312	Gearbox, Transfer			
0186	720526	Gearbox, Front, Inlet			
0319	730608	Gearbox, Front, Inlet			
0319	730830	Gearbox, Rear			
0779	720511	Gearbox, Front, Inlet			
3814	730206	Gearbox, Front, Inlet			
3814	730406	Number 3 Main Bearing			
3918	730911	Gearbox, Transfer			
3938	730810	Gearbox, Transfer			
3989	730712	Gearbox, Transfer, Bearing			
3993	730303	Gearbox, Transfer			
4136	720921	Constant Speed Drive			
4618	730430	Number 2 Main Bearing			
4690	730322	Gearbox, Front, Inlet			
8384	730928	Constant Speed Drive			
8990	730406	Gearbox, Front, Inlet			
9613	730122	Constant Speed Drive			
9966	720321	Gearbox, Front, Inlet			

Figure A-22.



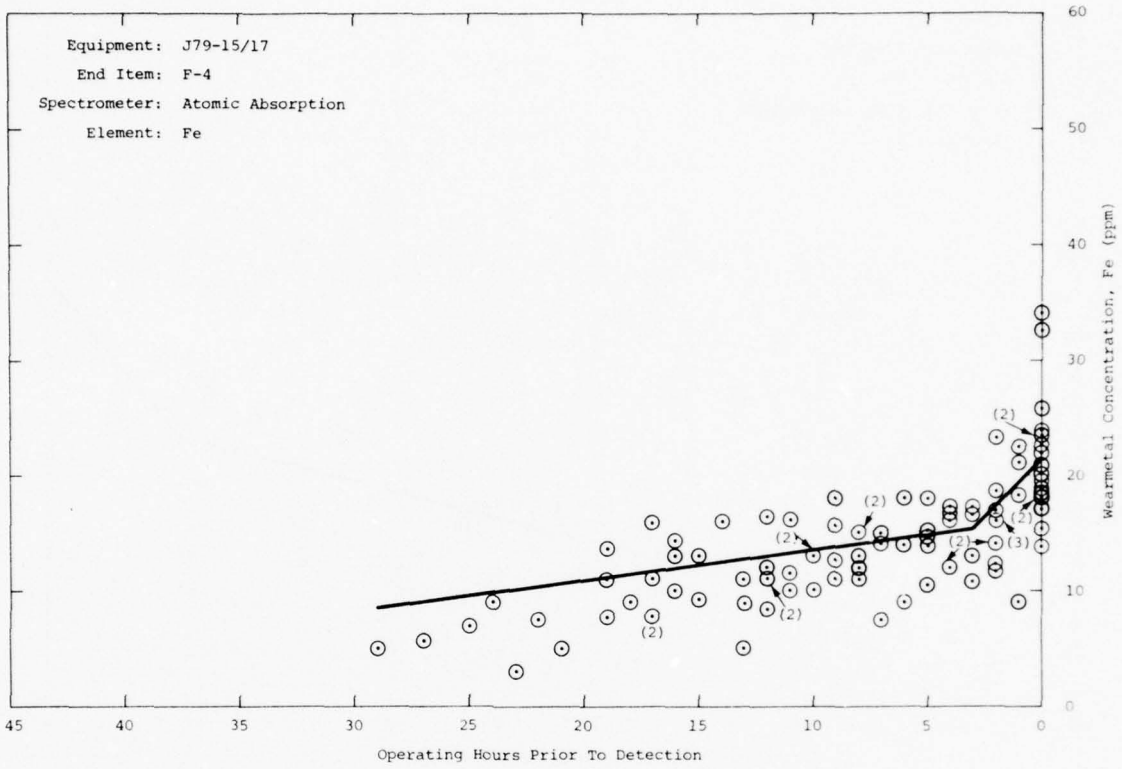
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0139	730312	Gearbox, Transfer			
0204	721220	Constant Speed Drive			
0644	730417	Constant Speed Drive			
0690	730614	Constant Speed Drive			
0845	730122	Constant Speed Drive			
3849	720802	Constant Speed Drive			
4136	720921	Constant Speed Drive			
4136	730404	Constant Speed Drive			
8236	730611	Constant Speed Drive			

Figure A-23.



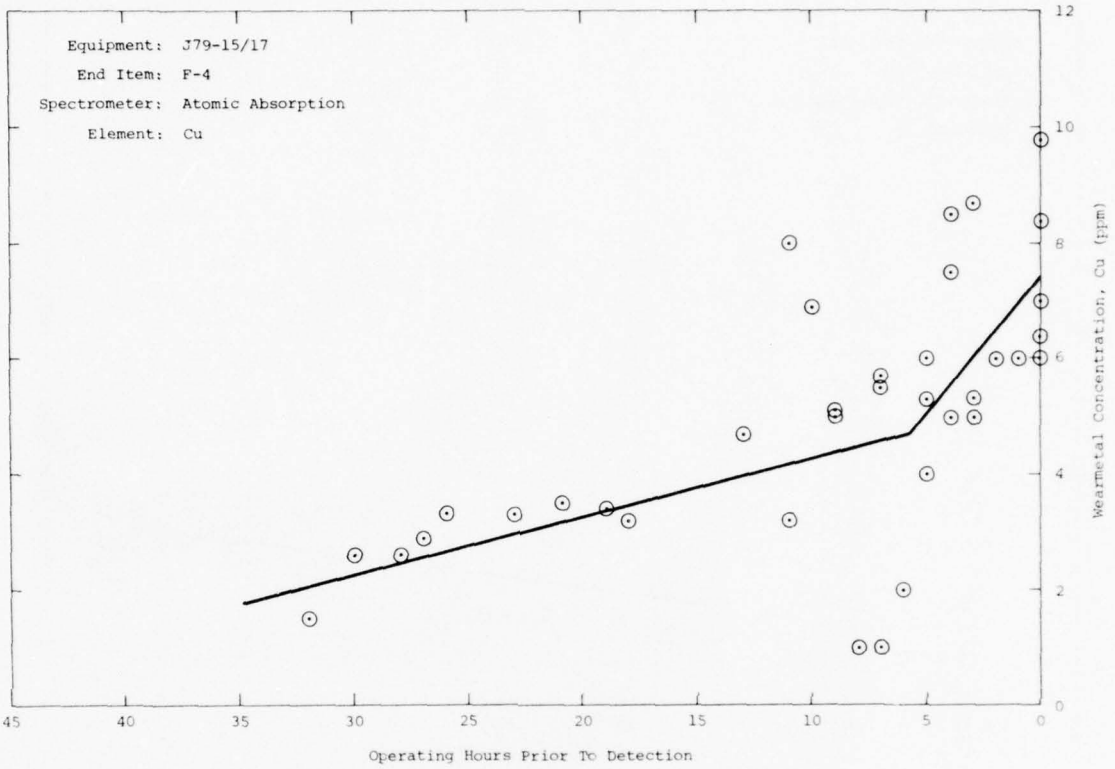
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0028	730217	Constant Speed Drive			
0139	730312	Gearbox, Transfer			
0644	730417	Constant Speed Drive			
4124	730913	Constant Speed Drive			
4136	730404	Constant Speed Drive			
4591	721124	Oil Pump, Compressor Section			
4591	721213	Gearbox, Front, Inlet			
9431	730426	Constant Speed Drive			

Figure A-24.



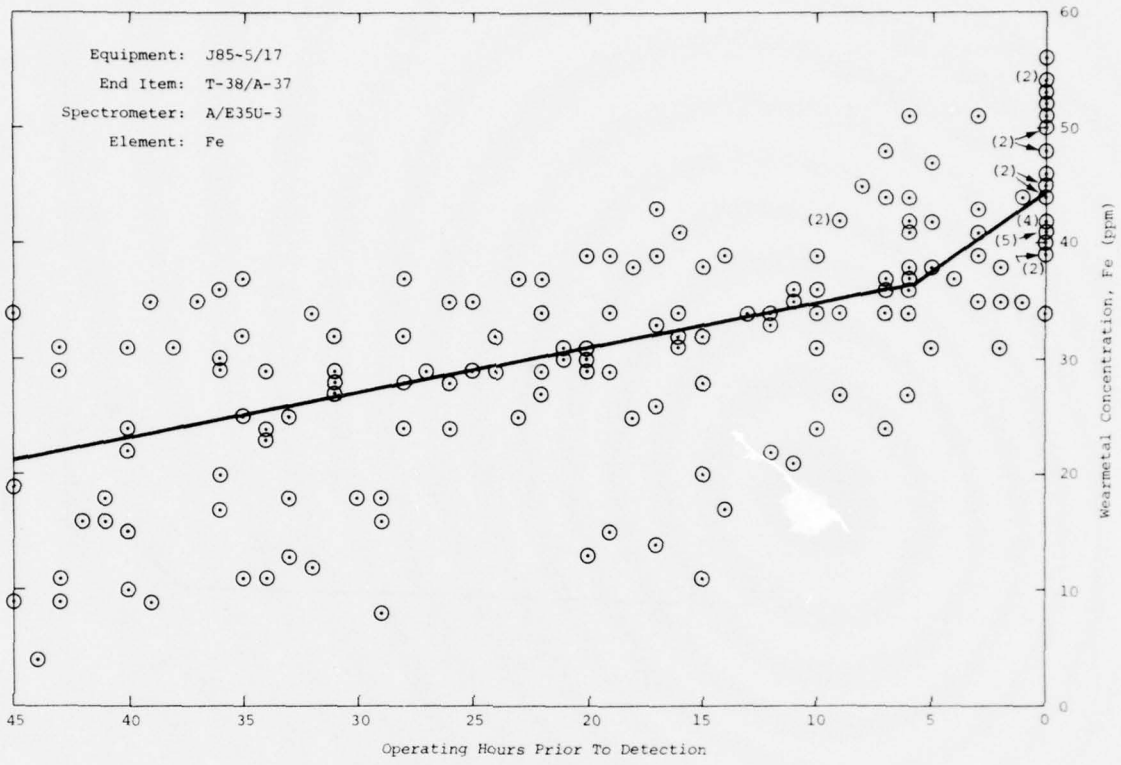
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0514	690500	Gearbox, Front, Inlet			
0627	690900	Gearbox, Transfer			
0662	700100	Gearbox, Front, Inlet			
0683	710817	Gearbox, Front, Inlet			
0790	710309	Gearbox, Front, Inlet			
0895	731031	Number 2 Main Bearing			
4095	691000	Gearbox, Transfer			
4127	730419	Gearbox, Front, Inlet			
4213	700100	Gearbox, Front, Inlet			
4567	700600	Constant Speed Drive			
4673	690400	Constant Speed Drive			
8113	691100	Unknown (K-30 Report)			
8680	730822	Gearbox, Front, Inlet			
9111	690900	Gearbox, Transfer			
9164	700100	Gearbox, Front, Inlet			
9315	691100	Unknown (K-30 Report)			
9433	730320	Gearbox, Front, Inlet			
9904	720223	Constant Speed Drive			

Figure A-25.



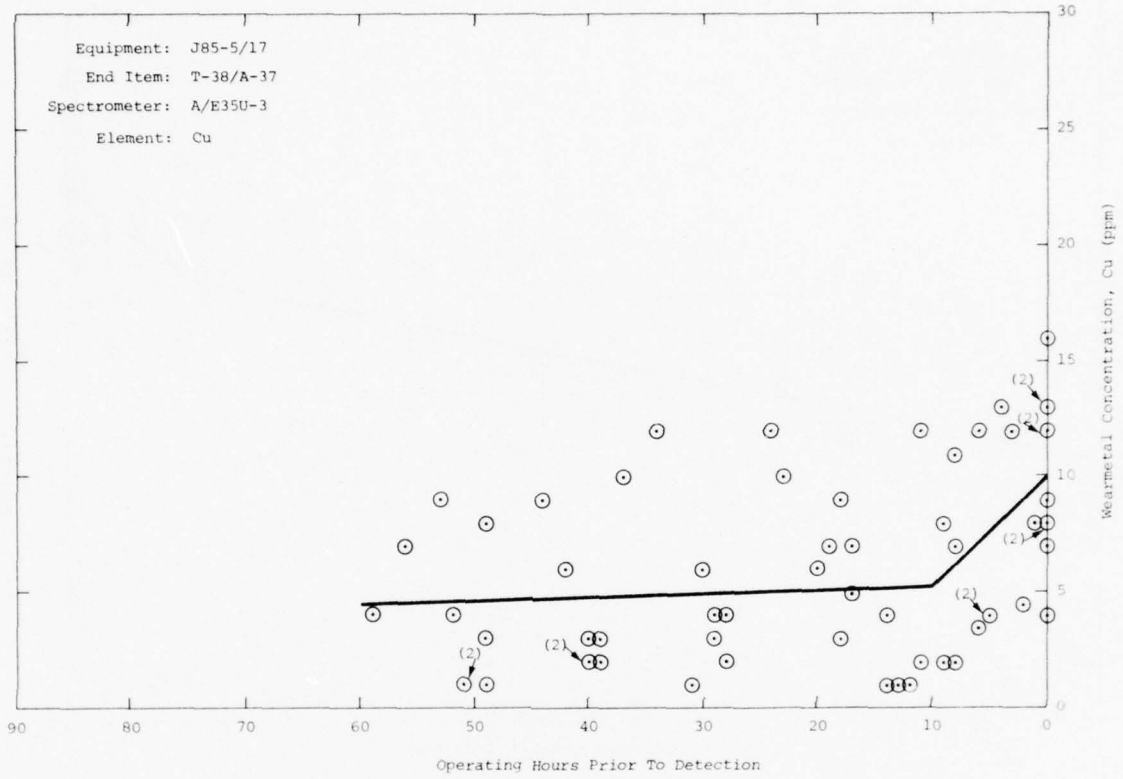
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0923	731116	Constant Speed Drive			
4306	690902	Number 1 Scavenge Pump			
4355	710903	Gearbox, Transfer			
4567	700200	Constant Speed Drive			
4801	690924	Number 1 Scavenge Pump			

Figure A-26.



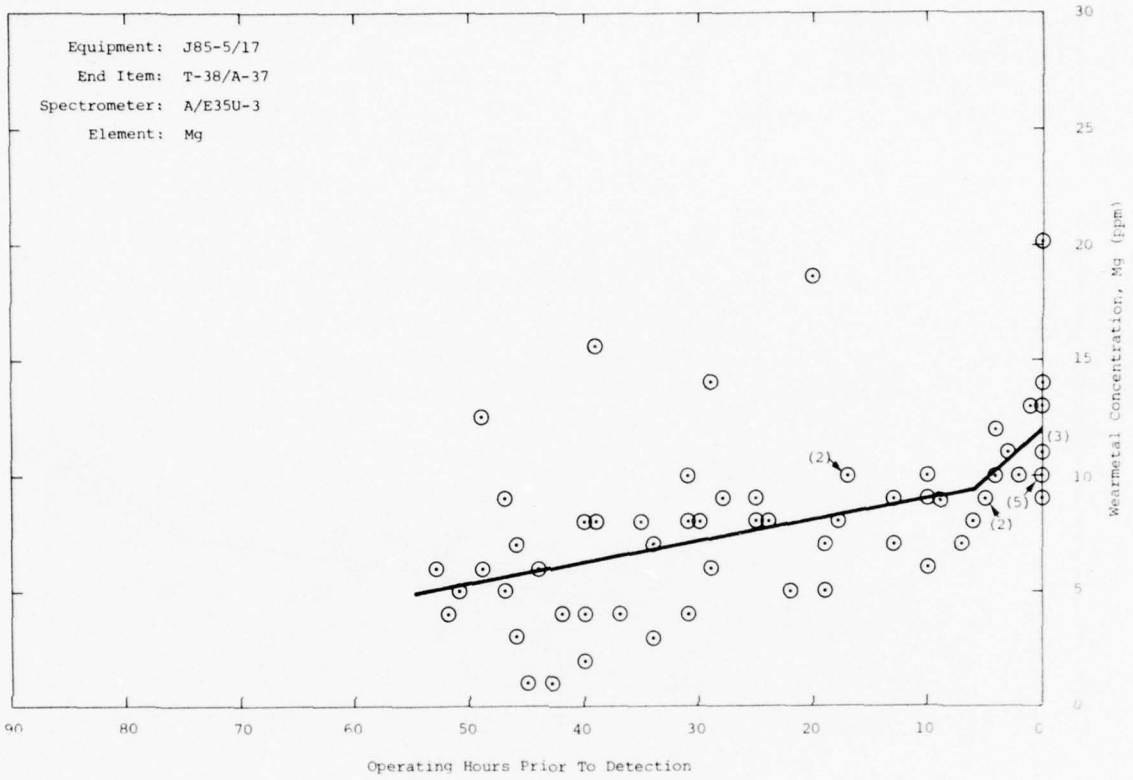
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0211	720707	Number 3 Main Bearing	1223	720727	Auxiliary Drives and Accessories
0279	730320	Auxiliary Drives and Accessories, Bearing	1250	720405	Auxiliary Drives and Accessories
0343	720824	Auxiliary Drives and Accessories, Bearing	1262	720907	Number 1 Main Bearing
0439	730223	Bearing, Accessory Drive, Air Inlet Section	1323	720829	Gearbox Rear, Bearing
0443	721108	Number 3 Main Bearing	1362	721130	Oil Pump, Compressor Section
0783	720518	Auxiliary Drives and Accessories, Bearing	1503	720713	Auxiliary Drives and Accessories, Bearing
0788	721114	Number 1 Main Bearing	1513	721207	Auxiliary Drives and Accessories, Bearing
0824	720713	Auxiliary Drives and Accessories, Bearing	1593	720324	Number 3 Main Bearing
0824	730226	Number 3 Main Bearing	1705	730226	Number 3 Main Bearing
0893	720914	Bearing, Accessory Drive, Air Inlet Section	2021	720725	Number 1 Main Bearing
1056	720619	Auxiliary Drives and Accessories, Bearing	2235	720411	Auxiliary Drives and Accessories, Bearing
1062	721110	Oil Pump, Compressor Section	2249	730514	Main Bearing(s)
1062	730712	Reduction Gearbox	2612	720822	Bearing, Accessory Drive, Air Inlet Section
1139	720622	Auxiliary Drives and Accessories, Bearing	2628	720731	Auxiliary Drives and Accessories, Bearing

Figure A-27.



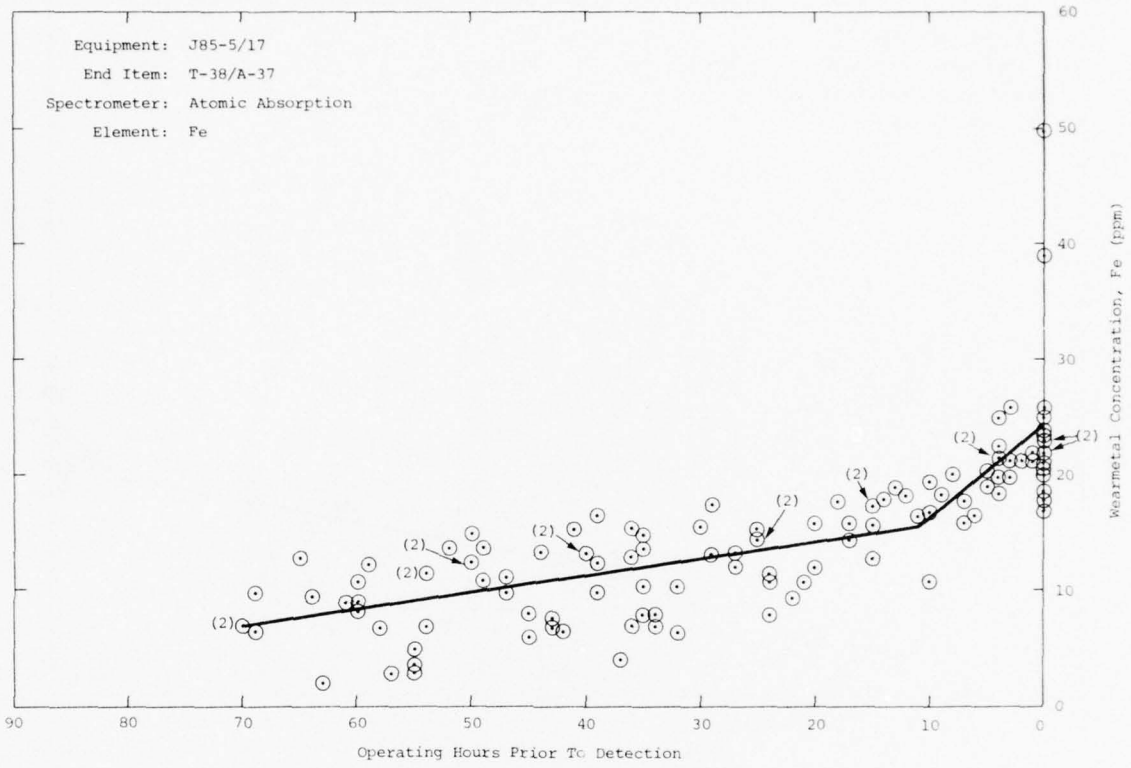
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0326	720314	Number 2 1/2 Main Bearing Housing			
1695	720725	Number 3 Main Bearing			
2021	720725	Number 1 Main Bearing			
2116	720730	Oil Pump, Compressor Section			
2462	720317	Number 3 Main Bearing Housing			
2491	721015	Oil Pump, Compressor Section			
2594	730320	Bearing, Accessory Drive, Air Inlet Section			
2733	730212	Main Bearing(s)			
2796	720725	Oil Pump, Compressor Section			
8873	730206	Number 2 Main Bearing			

Figure A-28.



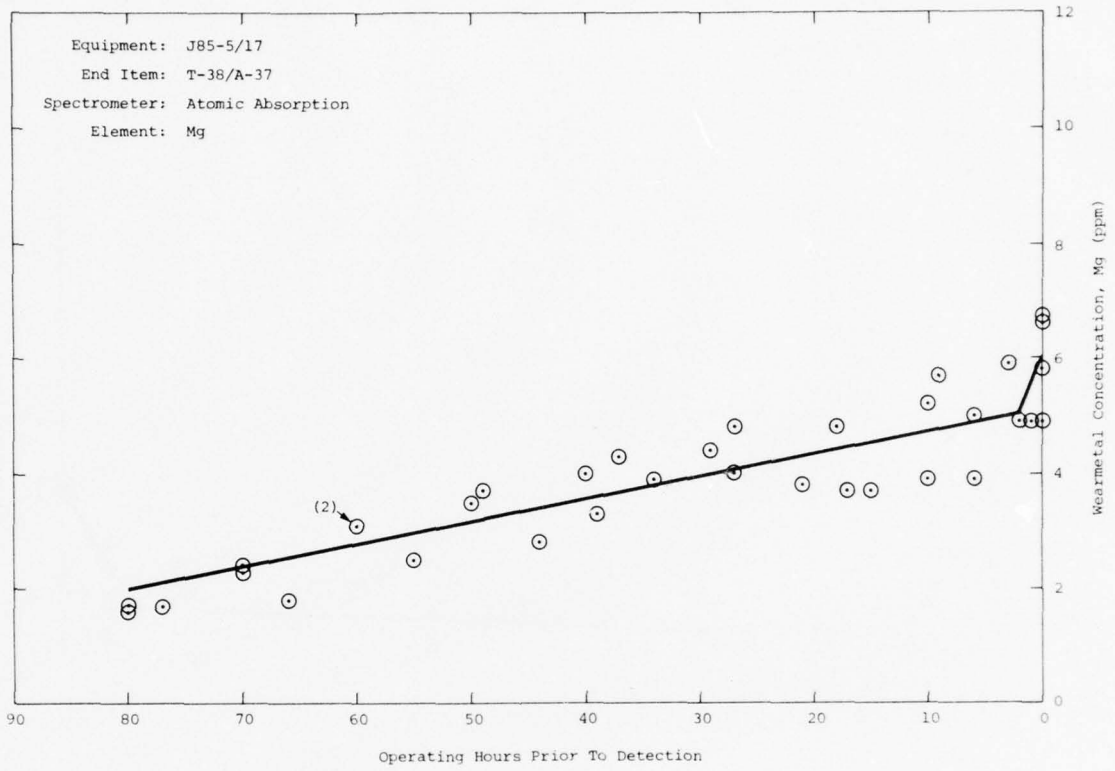
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0467	721219	Oil Pump, Compressor Section			
0791	720920	Oil Pump, Compressor Section			
0956	720804	Bearing, Accessory Drive, Air Inlet Section			
1062	721110	Oil Pump, Compressor Section			
1648	721127	Oil Pump, Compressor Section			
1816	720726	Oil Pump, Compressor Section			
1816	720906	Oil Pump, Compressor Section			
1816	730212	Oil Pump, Compressor Section			
2491	721017	Oil Pump, Compressor Section			
2599	730424	Oil Pump, Compressor Section			
2733	730212	Main Bearing(s)			
2796	720725	Oil Pump, Compressor Section			

Figure A-29.



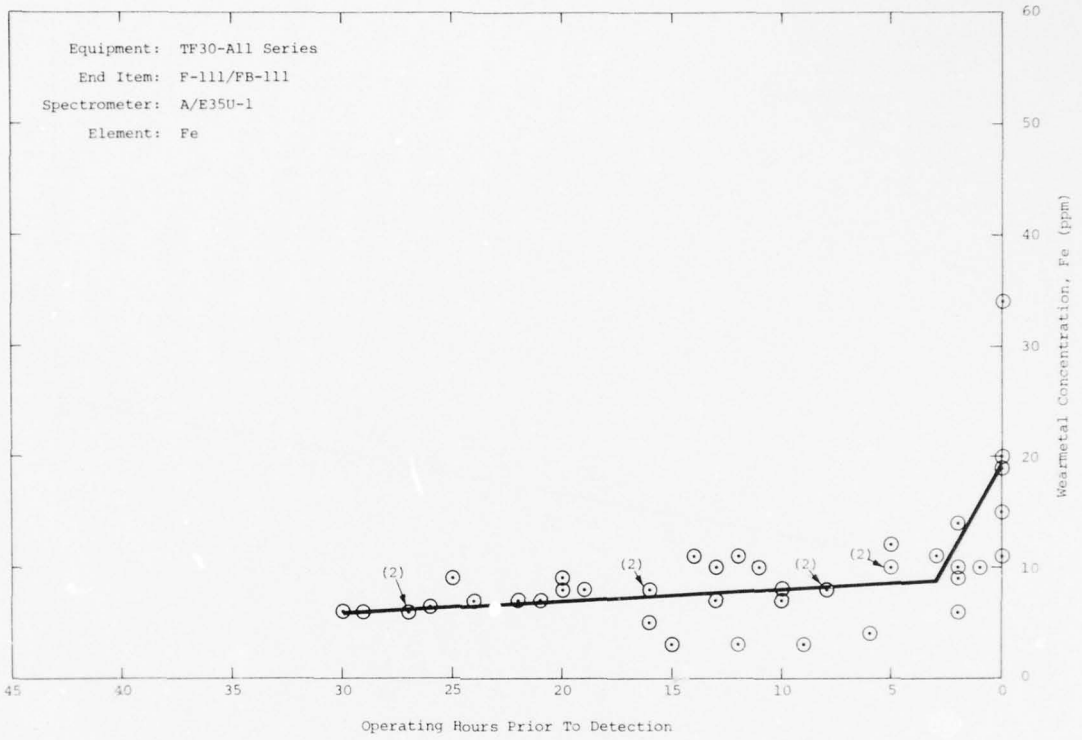
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0211	710708	Gearbox, Front, Inlet			
0258	710804	Number 3 Main Bearing			
0339	710831	Number 3 Main Bearing			
0470	711122	Auxiliary Drives and Accessories			
0492	720111	Number 3 Main Bearing			
0924	710808	Number 2 Main Bearing			
0969	710901	Oil Pump, Compressor Section			
1099	711110	Auxiliary Drives and Accessories			
1223	710909	Gearbox, Front, Inlet, Bearing			
1259	710519	Unknown (AFTO 119A Form)			
1435	710303	Number 3 Main Bearing			
1435	710610	Oil Pump, Compressor Section			
1679	710629	Number 3 Main Bearing			
1721	710605	Number 1 Main Bearing			
1845	710713	Bearing, Accessory Drive, Air Inlet Section			
2417	710920	Number 3 Main Bearing			

Figure A-30.



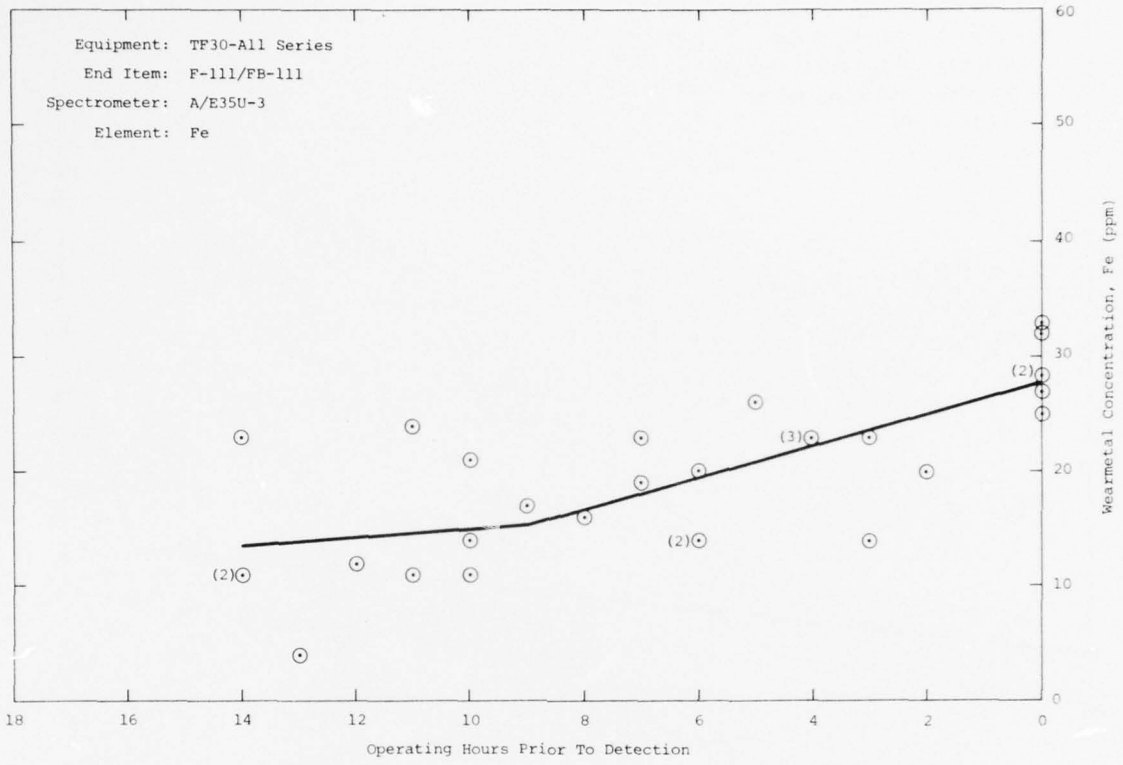
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0312	710914	Number 3 Main Bearing			
1306	710714	Gear, Air Inlet Section			
1435	710303	Number 3 Main Bearing			
1810	710722	Oil Pump, Compressor Section			

Figure A-31.



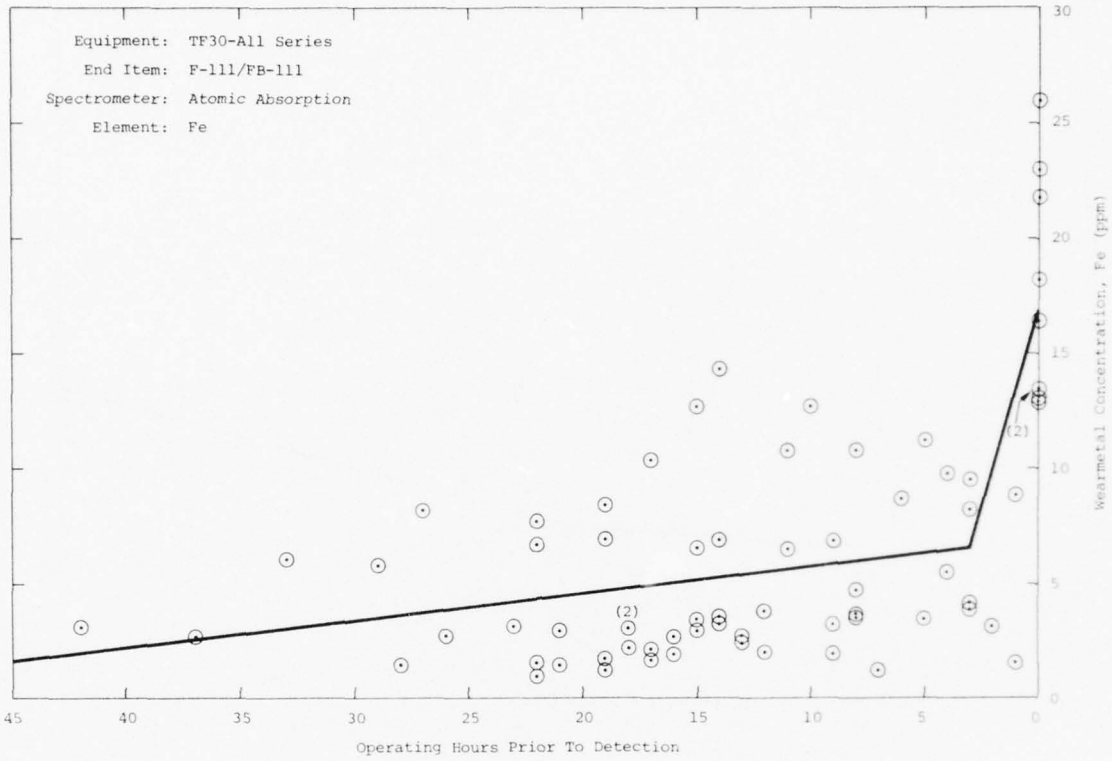
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
8765	730726	Reduction Gearbox			
8786	721214	Number 5 Main Bearing			
8833	720225	Number 2 Main Bearing			
8835	730122	Number 5 Main Bearing			
8993	720303	Number 5 Main Bearing			

Figure A-32.



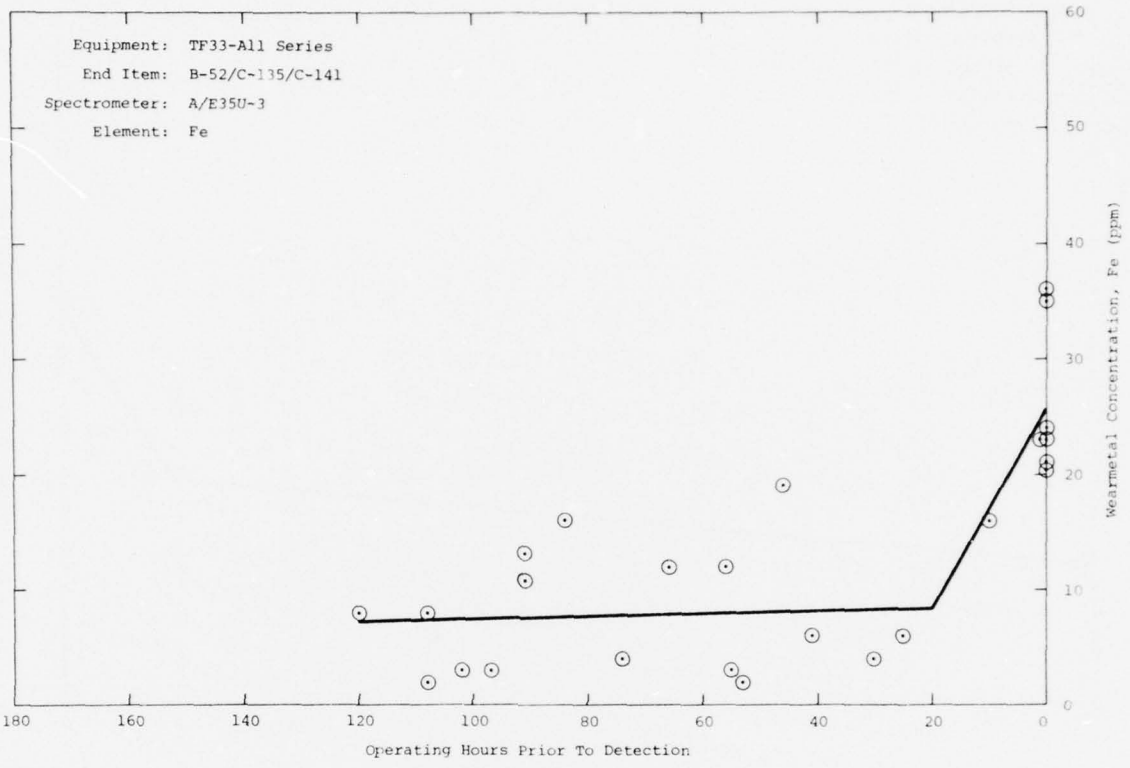
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
8677	730130	Number 3 Main Bearing			
8714	720309	Spacer, Bearing Seal, Compressor Section			
8934	730503	Number 3 Main Bearing			
8981	720725	Number 3 Main Bearing			
8987	720906	Oil Pump, Turbine Section			
9085	730126	Number 3 Main Bearing			

Figure A-33.



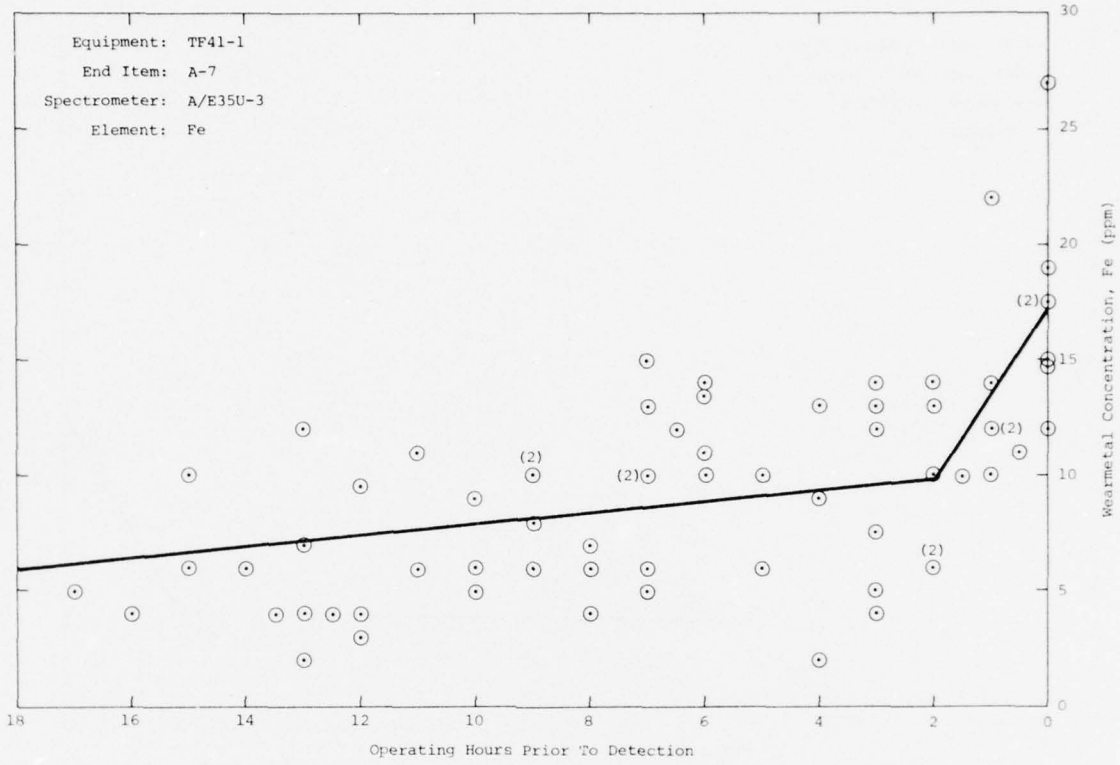
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
8673	710123	Number 3 Main Bearing			
8741	710629	Oil Pump			
8781	710309	Oil Pump			
8808	710618	Unknown (AFTO 119A Form)			
9126	710819	Number 5 Main Bearing			
9149	710119	Number 5 Main Bearing			
9153	701014	Number 5 Main Bearing			
9267	701204	Oil Pump			
9290	710112	Unknown (AFTO 119A Form)			

Figure A-34.



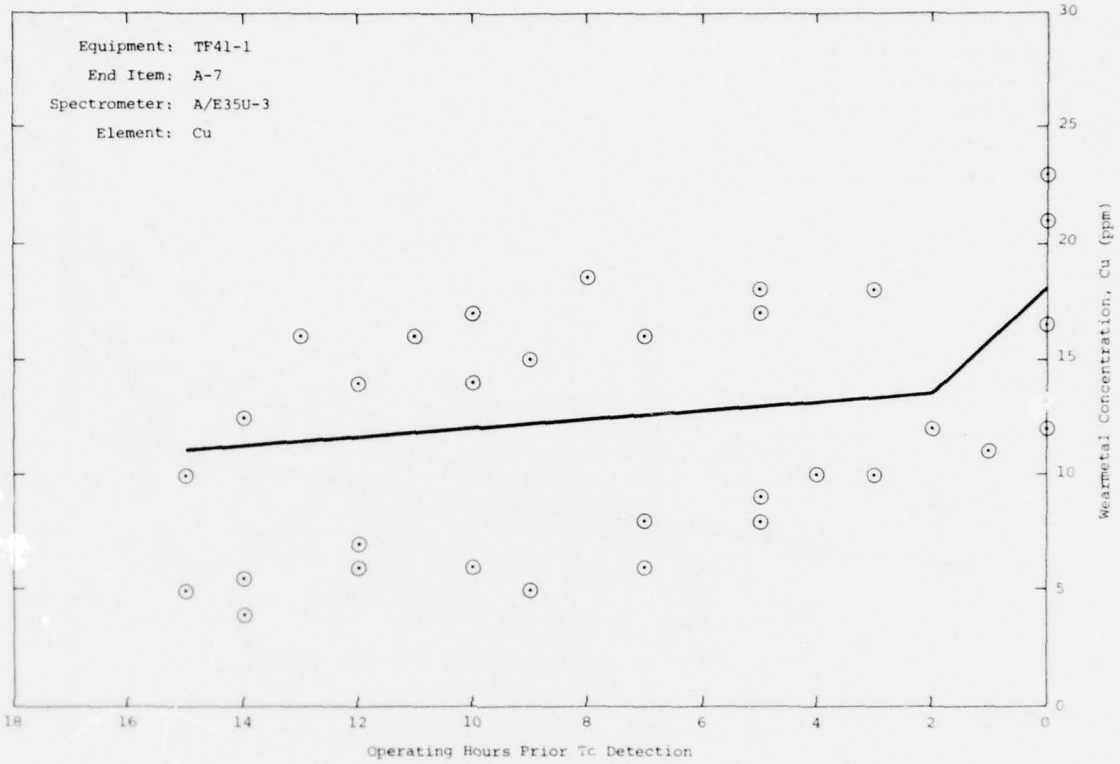
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
1015	721222	Unknown (SOAP Data Bank)			
1163	731026	Number 2 1/2 Main Bearing			
1219	730315	Number 4 Main Bearing			
1704	720404	Main Bearing(s)			
3106	731106	Number 1 Main Bearing			
3311	731014	Main Bearing(s)			

Figure A-35.



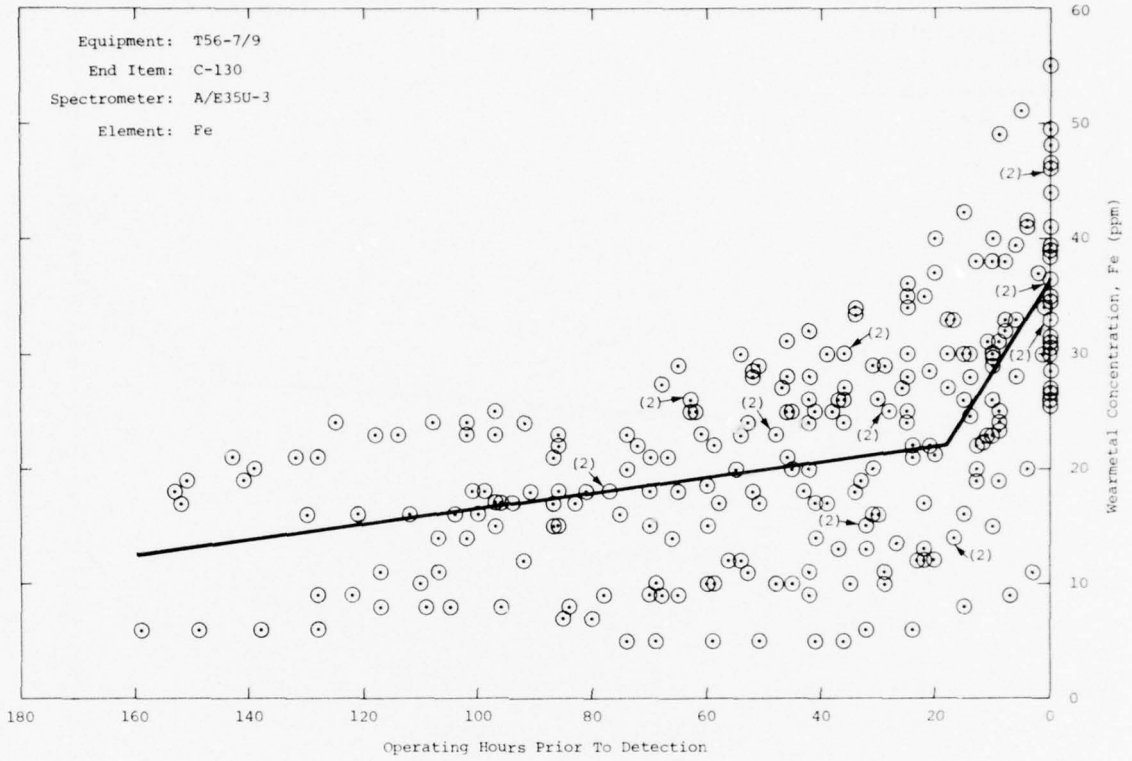
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
1103	731128	Unknown (AFTO 119A Form)			
1160	730214	Number 6 Main Bearing			
1176	740228	Unknown (AFTO 119A Form)			
1206	730822	Unknown (AFTO 119A Form)			
1207	730814	Unknown (AFTO 119A Form)			
1642	730915	Unknown (AFTO 119A Form)			
1677	730809	Unknown (AFTO 119A Form)			

Figure A-36.



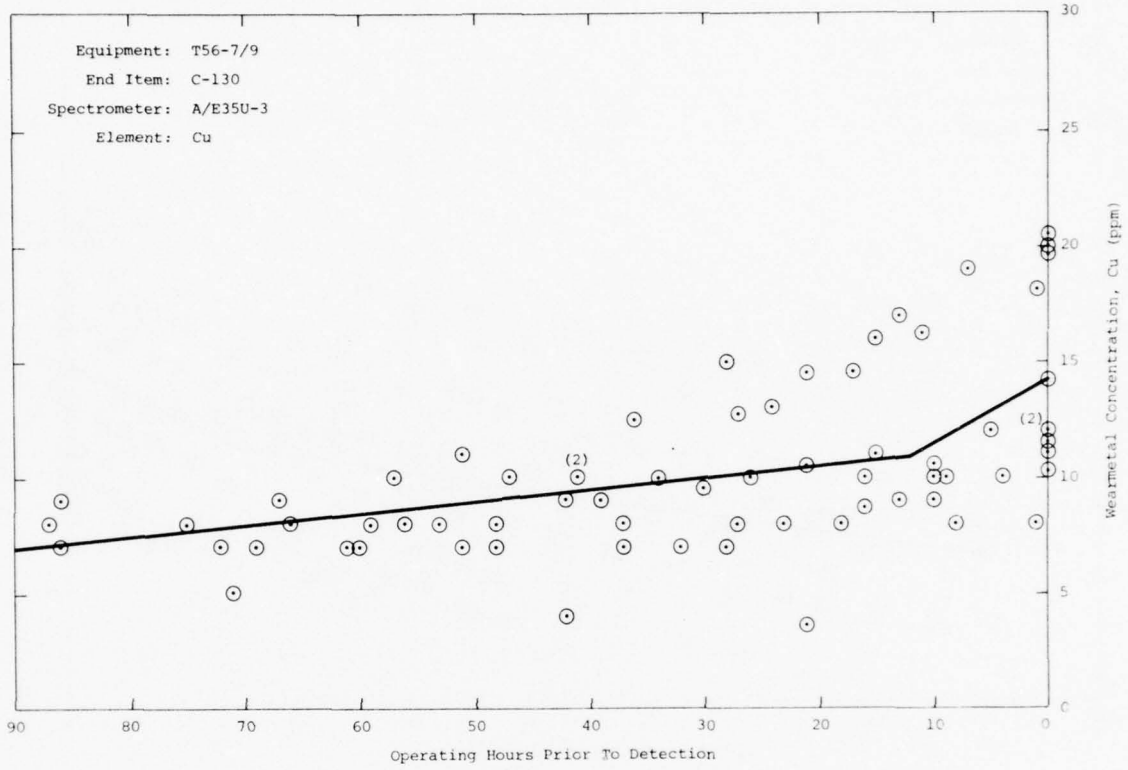
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
1059	730411	Number 1 Main Bearing			
1127	730810	Unknown (AFTO 119A Form)			
1161	740225	Unknown (AFTO 119A Form)			
1702	731029	Unknown (AFTO 119A Form)			

Figure A-37.



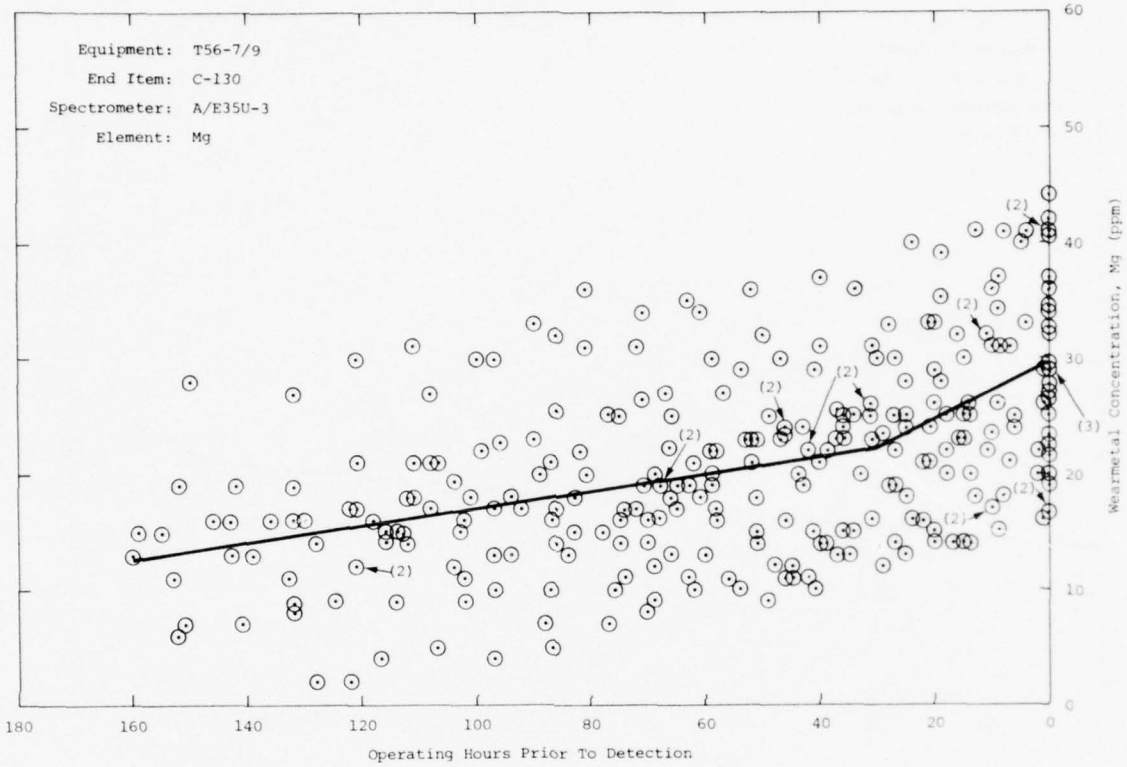
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
1779	720316	Propeller Shaft, Reduction Gearbox	3483	730602	Oil Pump, Reduction Gearbox
1973	730828	Oil Pump, Reduction Gearbox	3889	730426	Oil Pump, Reduction Gearbox
2136	730518	Reduction Gearbox, Bearing	3889	730619	Oil Pump, Reduction Gearbox
2219	730609	Oil Pump, Power Section	4183	731123	Reduction Gearbox
2232	730516	Oil Pump, Reduction Gearbox	4724	730921	Reduction Gearbox, Bearing
2419	721201	Reduction Gearbox, Bearing	4921	720703	Propeller Shaft, Reduction Gearbox
2620	721205	Oil Pump, Reduction Gearbox	4921	720816	Reduction Gearbox, Bearing
2626	730911	Oil Pump, Power Section; Scavenge Pump, Power Section, External	4995	731006	Oil Pump, Reduction Gearbox
2722	721110	Reduction Gearbox, Bearing	7148	730413	Oil Pump, Reduction Gearbox
2919	730910	Reduction Gearbox	7148	731203	Scavenge Pump, Rear Turbine
3023	720428	Propeller Shaft, Reduction Gearbox	7567	731004	Reduction Gearbox
3023	730427	Oil Pump, Reduction Gearbox			
3238	731121	Reduction Gearbox			
3311	720912	Oil Pump, Reduction Gearbox			
3430	720706	Reduction Gearbox			

Figure A-38.



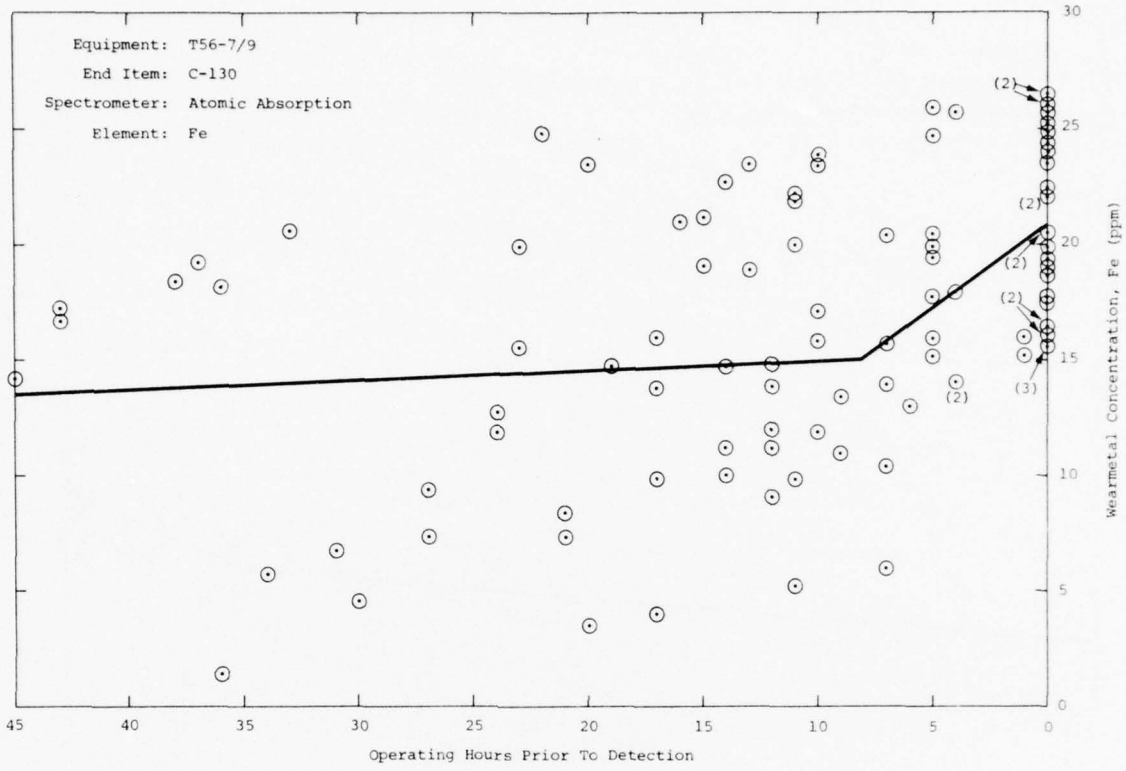
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
2219	730609	Oil Pump, Power Section			
2722	721110	Reduction Gearbox, Bearing			
3050	721228	Oil Pump, Reduction Gearbox			
3311	720912	Oil Pump, Reduction Gearbox			
4145	720619	Propeller Shaft, Reduction Gearbox			
4391	730504	Number 4 Main Bearing			
4419	720626	Propeller Shaft, Reduction Gearbox			
4868	730504	Oil Pump, Reduction Gearbox			
4921	720703	Propeller Shaft, Reduction Gearbox			

Figure A-39.



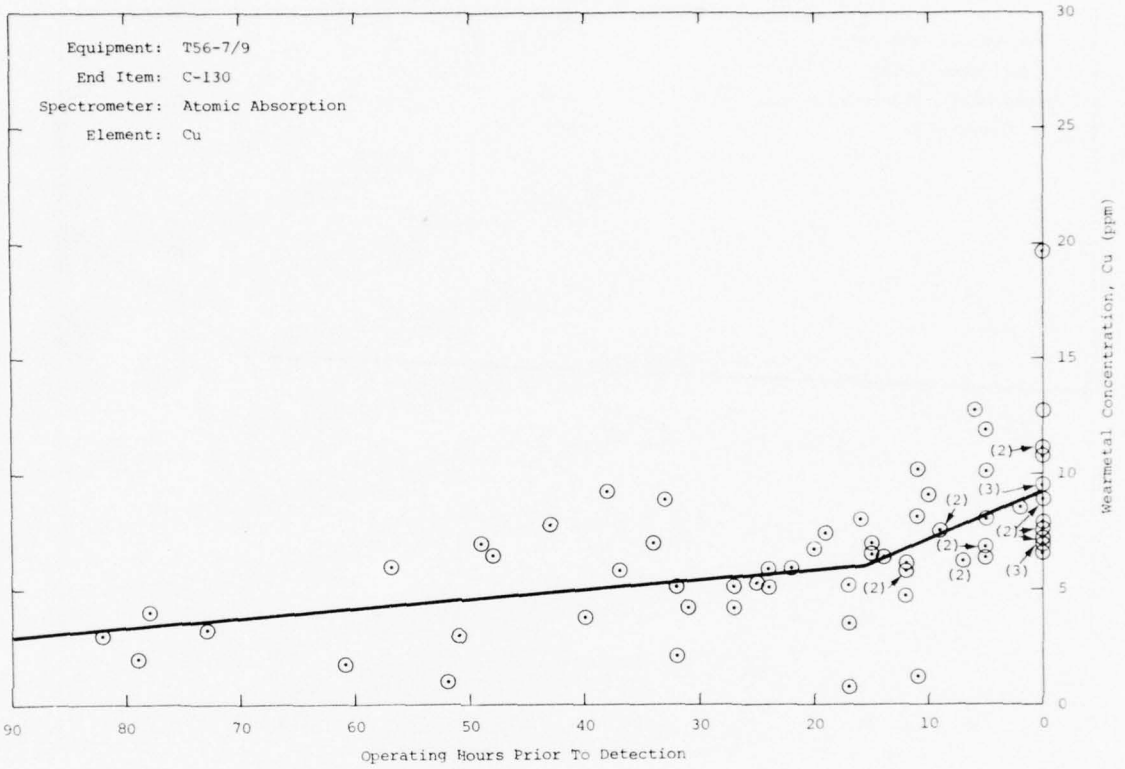
Equipment S/N	Date of Detection	Reported Malfunction
1383	720501	Oil Pump, Power Section
1640	731122	Oil Pump, Reduction Gearbox
1827	730213	Oil Pump, Reduction Gearbox
1973	730828	Oil Pump, Reduction Gearbox
2125	730718	Oil Pump, Reduction Gearbox
2219	730609	Oil Pump, Power Section
2620	721205	Oil Pump, Reduction Gearbox
2620	730410	Oil Pump, Reduction Gearbox
3023	730427	Oil Pump, Reduction Gearbox
3311	720912	Oil Pump, Reduction Gearbox
3430	720703	Reduction Gearbox
3457	730321	Reduction Gearbox, Bearing
3483	730602	Oil Pump, Reduction Gearbox
3889	730426	Oil Pump, Reduction Gearbox
3889	730619	Oil Pump, Reduction Gearbox
3948	730417	Oil Pump, Reduction Gearbox
3961	730427	Oil Pump, Reduction Gearbox
4081	720428	Propeller Shaft, Reduction Gearbox
4387	730503	Oil Pump, Reduction Gearbox
4414	730320	Oil Pump, Reduction Gearbox
4414	730613	Oil Pump, Reduction Gearbox
4758	730517	Oil Pump, Reduction Gearbox
4868	730504	Oil Pump, Reduction Gearbox
4881	730227	Reduction Gearbox, Bearing
5523	720927	Oil Pump, Reduction Gearbox
7614	730502	Oil Pump, Reduction Gearbox

Figure A-40.



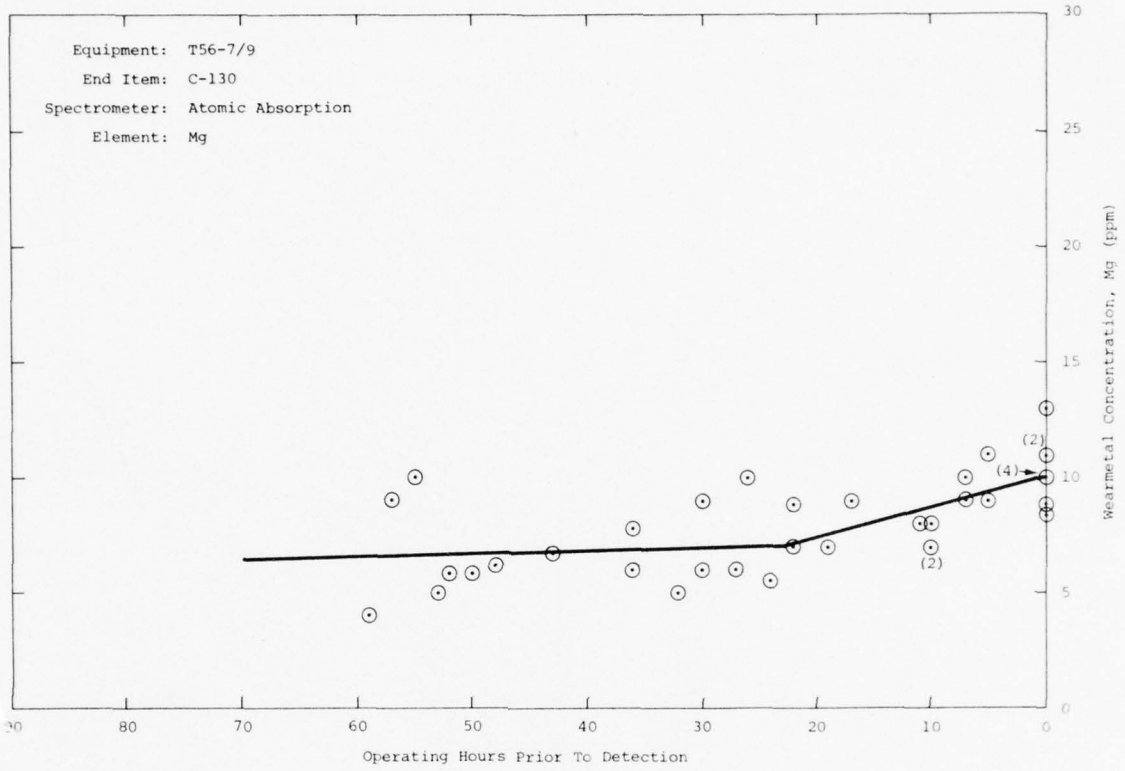
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0930	700217	Oil Pump, Reduction Gearbox	3907	690200	Oil Pump, Reduction Gearbox
1724	700611	Oil Pump, Reduction Gearbox	4129	700211	Reduction Gearbox
1749	700903	Oil Pump, Reduction Gearbox	4182	700930	Reduction Gearbox
1749	700921	Reduction Gearbox	4317	690200	Oil Pump, Reduction Gearbox
1805	700902	Oil Pump, Reduction Gearbox	4341	700824	Oil Pump, Reduction Gearbox
1830	710727	Oil Pump, Reduction Gearbox	4378	700824	Reduction Gearbox
1957	700420	Oil Pump, Reduction Gearbox	4432	700828	Oil Pump, Reduction Gearbox
1957	700708	Oil Pump, Reduction Gearbox	4747	700612	Oil Pump, Reduction Gearbox
2047	700604	Oil Pump, Reduction Gearbox	4753	690200	Oil Pump, Reduction Gearbox
2221	700901	Unknown (K-30 Report)	4798	700420	Oil Pump, Reduction Gearbox
3187	690200	Oil Pump, Reduction Gearbox	4864	700604	Oil Pump, Reduction Gearbox
3292	691211	Oil Pump, Reduction Gearbox	7168	700605	Oil Pump, Reduction Gearbox
3438	700518	Oil Pump, Reduction Gearbox	7636	700715	Number 4 Main Bearing
3874	700922	Reduction Gearbox	7636	701013	Number 4 Main Bearing

Figure A-41.



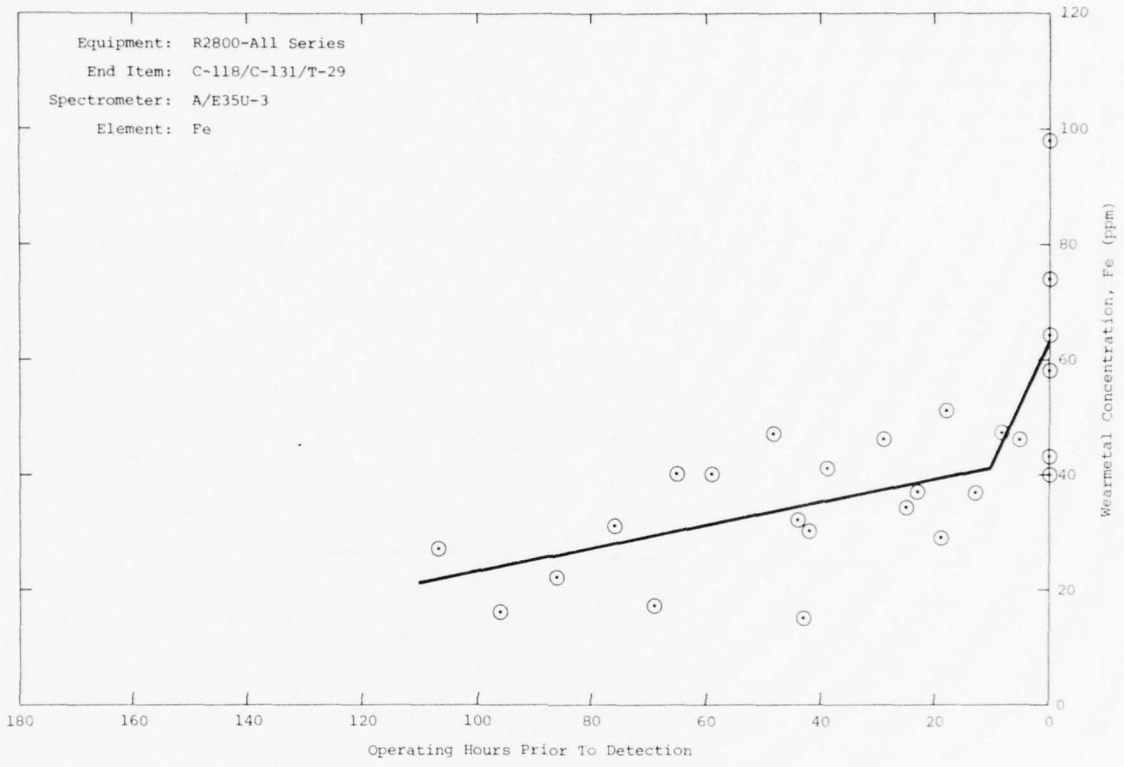
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0596	720829	Sump Pump, Reduction Gearbox	4129	691114	Oil Pump, Reduction Gearbox
1298	720706	Sump Pump, Reduction Gearbox	4341	700824	Oil Pump, Reduction Gearbox
1298	720829	Oil Pump, Air Inlet Section	4381	710610	Propeller Shaft, Reduction Gearbox
1805	700901	Oil Pump, Reduction Gearbox	4432	700828	Oil Pump, Reduction Gearbox
1852	691118	Oil Pump, Reduction Gearbox	4798	700420	Oil Pump, Reduction Gearbox
1852	700420	Oil Pump, Reduction Gearbox	4864	700604	Oil Pump, Reduction Gearbox
1957	700420	Oil Pump, Reduction Gearbox			
2087	690800	Oil Pump, Reduction Gearbox			
2443	690711	Oil Pump, Reduction Gearbox			
2956	690716	Oil Pump, Reduction Gearbox			
3461	701110	Oil Pump, Reduction Gearbox			
3869	700824	Oil Pump, Reduction Gearbox			
3976	690200	Oil Pump, Reduction Gearbox			

Figure A-42.



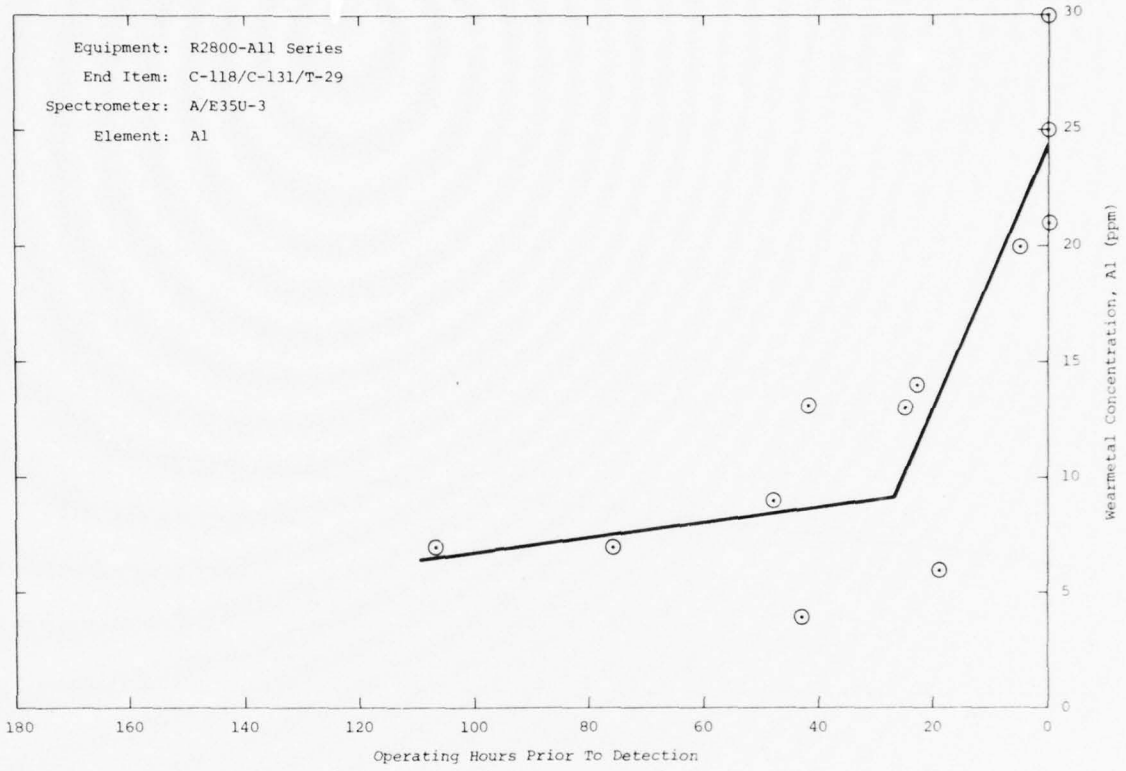
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0580	720802	Sump Pump, Reduction Gearbox			
1284	720216	Sump Pump, Reduction Gearbox			
1310	720327	Sump Pump, Reduction Gearbox			
1447	720208	Sump Pump, Reduction Gearbox			
1447	720216	Sump Pump, Reduction Gearbox			
1552	720617	Oil Pump, Reduction Gearbox			
1574	720614	Oil Pump, Reduction Gearbox			
2221	700901	Unknown (K-30 Report)			
3189	691112	Oil Pump, Reduction Gearbox			

Figure A-43.



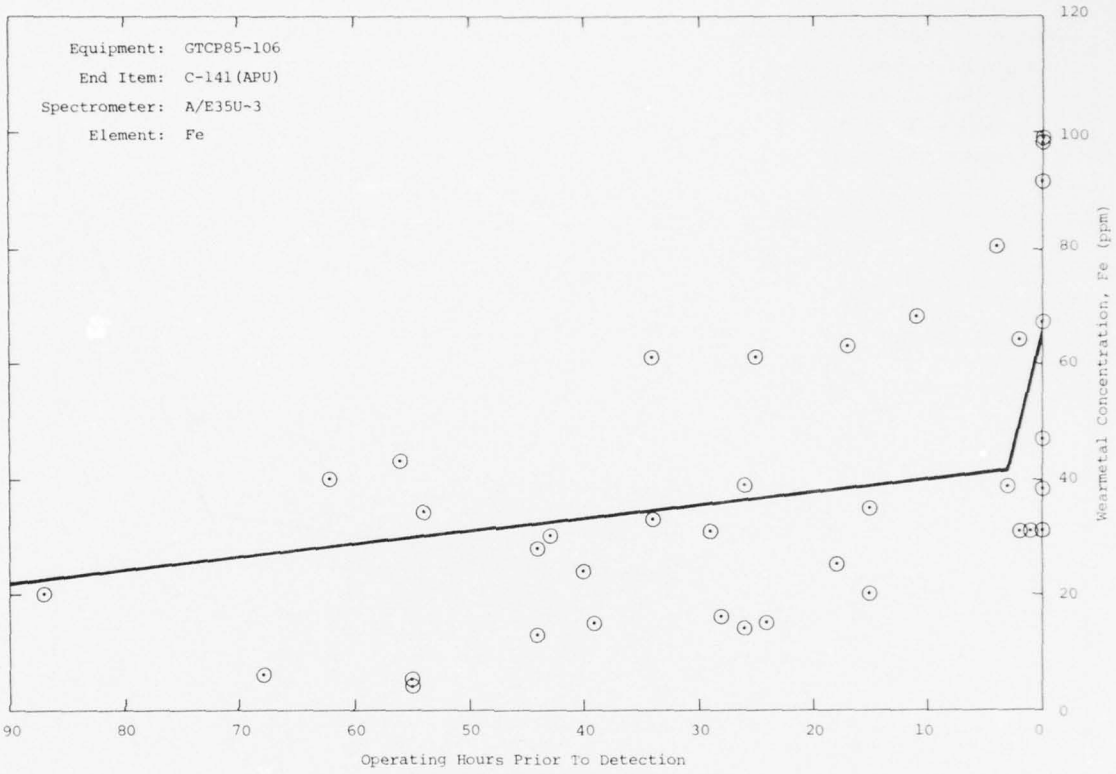
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0928	730626	Unknown (SOAP Data Bank)			
1036	730331	Cylinder			
2951	721211	Valve Guide			
3517	721024	Cylinder			
4013	730712	Unknown (AFTO 119A Form)			
5315	720914	Plate, Main Power			

Figure A-44.



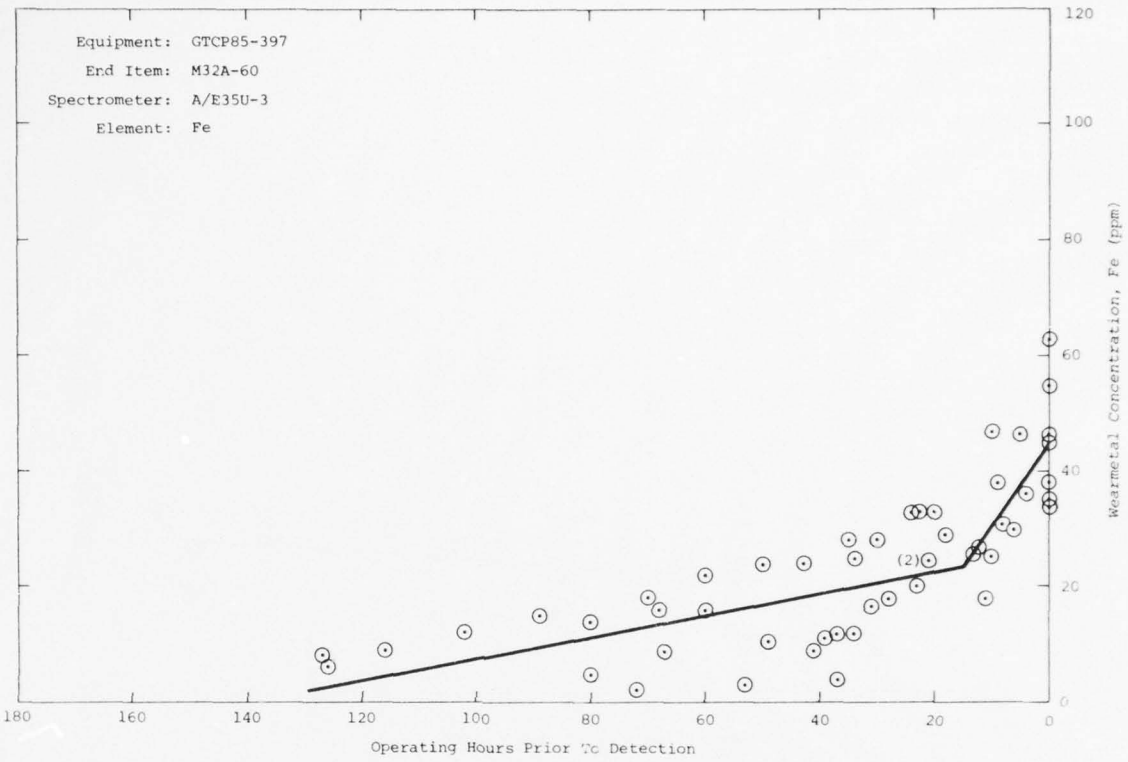
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0928	730626	Unknown (SOAP Data Bank)			
1036	730331	Cylinder			
3517	721024	Cylinder			

Figure A-45.



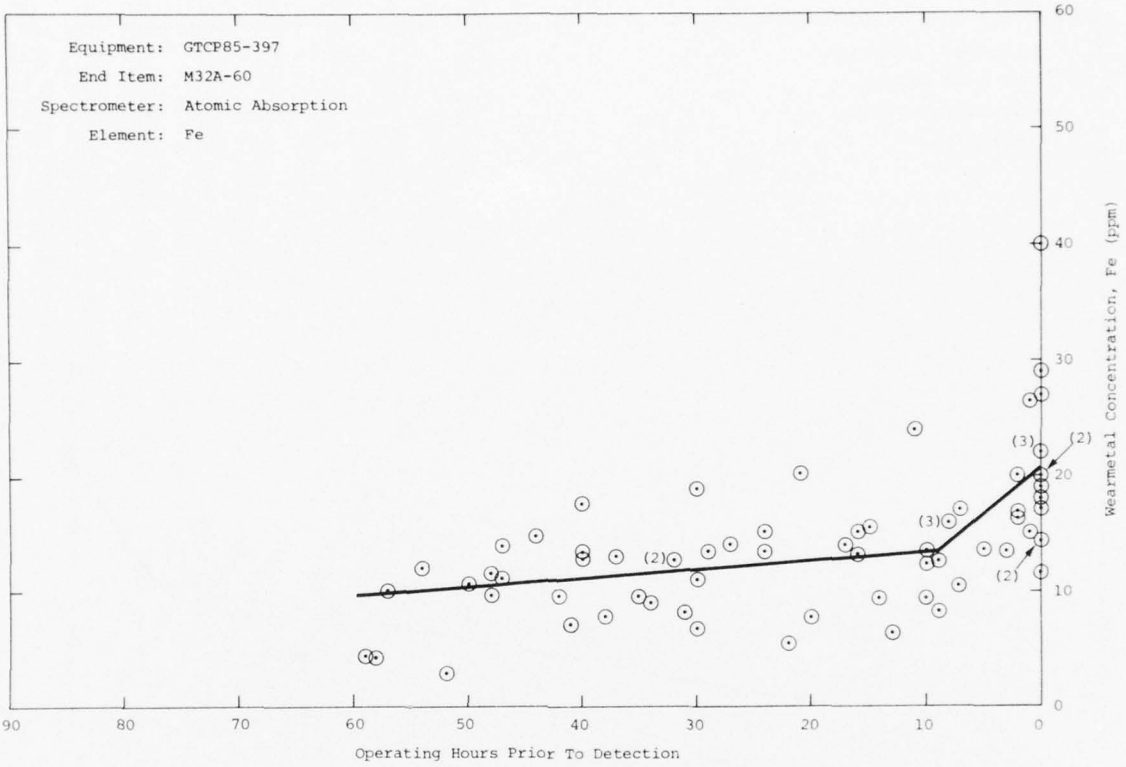
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
8816	720613	Bearing, Roller, Gas Turbine Motor			
8842	730727	Turbine Shaft, Gas Turbine Motor			
8974	720912	Gas Turbine Motor			
8985	720405	Gas Turbine Motor			
9028	730415	Gas Turbine Motor			
9087	730723	Gas Turbine Motor			
9098	730403	Bearing, Ball, Gas Turbine Motor			

Figure A-46.



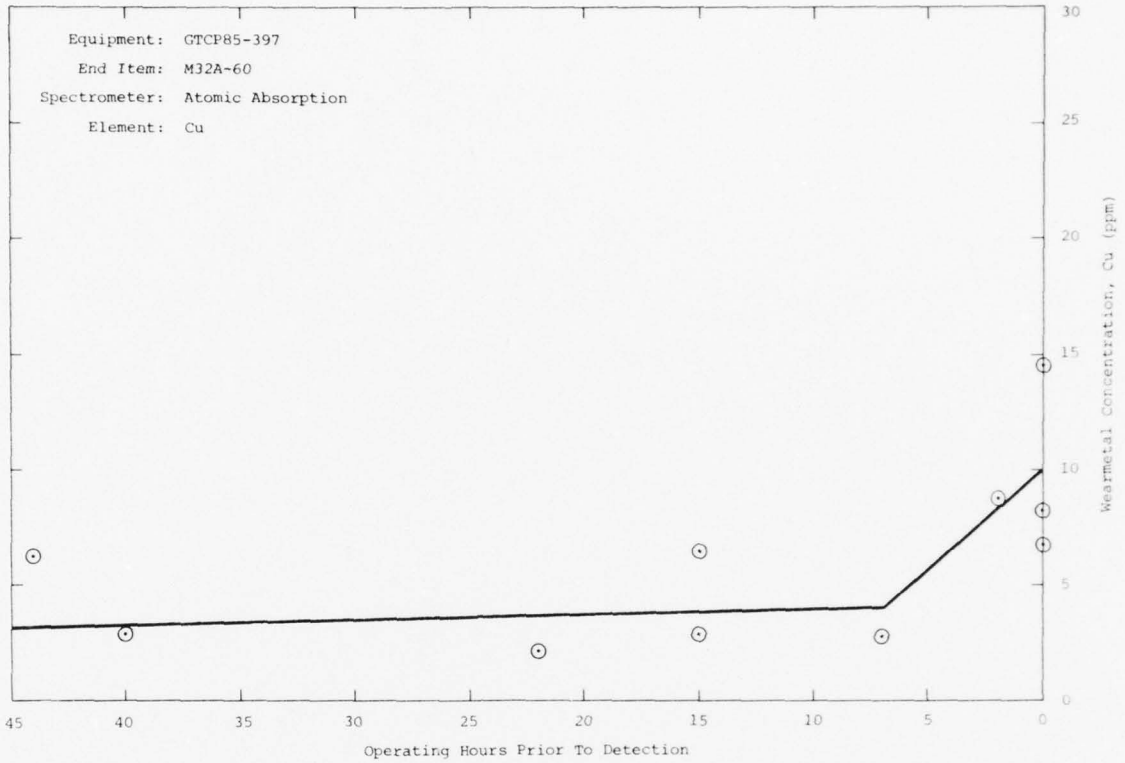
Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0603	720426	Turbine Motor			
0729	730914	Bearing, Turbine Motor			
1178	720907	Oil Pump, Turbine Motor			
1324	720308	Bearing, Roller, Turbine Motor			
1464	730329	Bearing, Roller, Turbine Motor			
1514	721130	Oil Pump, Turbine Motor			
9736	720621	Bearing, Turbine Motor			

Figure A-47.



Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0020	691119	Bearing, Gearbox			
0108	700209	Bearing, Rear Compressor			
0225	710623	Bearing, Ball, Turbine Motor			
0233	710125	Gear, Turbine Motor			
0321	710301	Turbine Motor			
0447	700119	Bearing, Gearbox			
0507	710611	Bearing, Ball, Turbine Motor			
0528	691021	Bearing, Turbine Section			
0712	691229	Bearing, Gearbox			
0837	690923	Bearing, Front Turbine			
0866	710903	Bearing, Ball, Turbine Motor			
0900	710317	Gear, Turbine Motor			
0908	720723	Gear, Turbine Motor			
0995	720314	Bearing, Ball, Turbine Motor			

Figure A-48.



Equipment S/N	Date of Detection	Reported Malfunction	Equipment S/N	Date of Detection	Reported Malfunction
0148	691201	Bearing, Rear Compressor			
0528	691021	Bearing, Turbine Section			
0837	690923	Bearing, Front Turbine			

Figure A-49.

APPENDIX B

REVISION OF TECHNICAL MANUAL "SPECTROMETRIC OIL ANALYSIS PROGRAM (SOAP) EVALUATION CRITERIA"

1. PURPOSE

The SOAP Wearmetal Decision Tables (Section 5) are designed to assist the SOAP laboratory and maintenance personnel in identifying incipient mechanical failures of oil-wetted components and in isolating suspected discrepancies. SOAP operating procedures are contained in T.O. 42B2-1-9.

2. USE

The SOAP Wearmetal Decision Tables are aids in determining the significance of wearmetal contamination. Analysis readings vary and are related to time since oil change. Therefore, when wearmetal concentration values indicate a definite increasing trend, it is recommended that equipment oil not be changed. Mechanical systems which approach the "T" code value must be kept under close surveillance by SOAP laboratory and maintenance personnel.

The Wearmetal Decision Tables were derived from historical data exhibiting a significant trend in wearmetal buildup prior to confirmation of an oil-wetted component discrepancy. Although the total wearmetal concentration value is generally used to indicate the condition of a mechanical component, attention must also be given to the rate of increase of concentration between oil samples. Rapid, significant increases in wearmetal content, even though they do not exceed the "T" code value, are good indicators of impending equipment failure. When evaluation of the significance of the test results becomes difficult, a graph plotting wearmetal concentration values against equipment time may be helpful.

In addition to the Wearmetal Decision Tables, metallic composition of oil-wetted components is provided with major alloy elements enclosed in a fine-line box. Identification of metallic composition of oil-wetted components, coupled with SOAP wearmetal trends, will serve as an additional maintenance tool in isolating a possible mechanical discrepancy. However, it must be emphasized that overall discrepancy isolation is limited to cases in which a distinctive combination of wearmetal elements exists, since similar metallic materials are utilized throughout oil-wetted components. For example, if iron is the only element which appears excessive, it would be of little value in isolating a particular problem area in an aircraft engine, since practically all areas of the engine contain some iron. But if another element is also indicated, the discrepancy may then be confined to a specific area.

3. GENERAL PROCEDURE

The following general procedure is to be followed by the laboratory analyst in arriving at a decision as to what action to recommend based on wearmetal concentration values. The numbers in the body of the table represent spectrometer readings in parts per million (ppm). The prescribed action codes correspond to those defined in T.O. 42B2-1-9; the definitions are repeated at the bottom of each page of tables for convenience. The procedure is designed so that an abnormally high reading for any wearmetal will automatically result in a request for a redtagged sample before a maintenance action is recommended. If the redtagged sample verifies the original indication, appropriate action should be taken in accordance with the prescribed codes.

Routine Samples

For all routine samples (samples taken in accordance with prescribed sampling intervals or Command policies), the following procedure applies:

a. Using the Decision Table, determine the recommendation code for each element.

b. If recommendation code for all elements is "A", no action is required.

c. If recommendation code for any element is "T", ground the unit, request a redtagged sample as soon as possible; do not change oil (code "P").

d. If recommendation code for any element is other than "A", but no element has a code of "T", execute requirements of the indicated code which prescribes the most severe action.

Redtagged Samples

For all redtagged samples (samples requested by the laboratory as a result of step c or d, above), the following procedure applies:

a. Determine recommendation code for each element.

b. If more than one recommendation code is indicated, use the one which prescribes the most severe action.

c. When using recommendation codes "K" or "T", use the Diagnostic and Troubleshooting Guides to determine possible area(s) of discrepancy.

4. WEARMETAL SYMBOL IDENTIFICATION

Wearmetal symbols used within this appendix are identified as follows:

Ag - Silver	Cr - Chromium	Mg - Magnesium	Ni - Nickel	Sn - Tin
Al - Aluminum	Cu - Copper	Mn - Manganese	Pb - Lead	Ti - Titanium
Co - Cobalt	Fe - Iron	Mo - Molybdenum	Si - Silicon	V - Vanadium
	W - Tungsten		Zn - Zinc	

5. WEARMETAL DECISION TABLES AND DIAGNOSTIC GUIDANCE

Index by Equipment

Index by End Item

J33-35
(T-33)

A/E 35 U-1

	Fe	Ag	Al	Cr	Cu	Mg
A	0-11	0-1	0-3	0-2	0-2	0-2
N	12-14	2	4	3	3	3-4
K	15-19	3	5-6	4	4-5	5-7
T	20+	4+	7+	5+	6+	8+

A/E 35 U-3

	Fe	Ag	Al	Cr	Cu	Mg
A	0-15	0-2	0-3	0-2	0-2	0-1
N	16-18	3	4	3	3	2
K	19-24	4	5-6	4	4-5	3-4
T	25+	5+	7+	5+	6+	5+

Atomic Absorption

	Fe	Ag	Al	Cr	Cu	Mg
A	0-8	0	0-3	0-2	0-2	0-1
N	9-10	1	4	3	3	2
K	11-13	2	5-6	4	4-5	3
T	14+	3+	7+	5+	6+	4+

Codes:

A – Continue routine sampling.

N – Do not change oil, submit redtagged sample after each flying day.

K – Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded.

T – Ground unit, examine for suspected discrepancy. Advise laboratory of findings.

If Fe and Mg suddenly increase, recommend inspection of the main starter housing for discrepancy. High Fe and Mg usually indicate accessory gear section upper idler gear defect. Any rapid increase in Mg is usually indicative of defective lube pump. A slow but steady increase in Mg is indicative of support starting gear shaft rear bearing cage coming loose and chafing attaching support. Copper is a critical wearmetal. When Cu increases in any amount, close surveillance should be maintained for defects of main and/or accessory bearings. Due to sampling technique, samples are often contaminated. Fe and Mg usually appear excessive with contaminated samples; therefore, caution must be exercised. If high Mg only, check for water in sample.

Fe	Accessory drive assembly gears and bearings Main bearing rings, balls/rollers and housing
Fe & Cu	Accessory drive assembly oil pump housing
Cu & Fe Si	No. 3 bearing cages
Cu & Ag Fe Pb	Nos. 2 and 4 bearing cages
Cu & Ag Zn Pb	No. 1 bearing cages
Al	Main bearing seals
Mg	Accessory drive assembly casings

J57-13/23/55
(F-101/F-102)

A/E 35 U-1

	Fe	Ag	Al	Cr	Cu	Mg
A	0-11	0-1	0-3	0-2	0-3	0-3
N	12-14	2	4	3	4	4-5
K	15-19	3	5-6	4-5	5-7	6-7
T	20+	4+	7+	6+	8+	8+

A/E 35 U-3

	Fe	Ag	Al	Cr	Cu	Mg
A	0-11	0-1	0-3	0-3	0-3	0-5
N	12-14	2	4-5	4	4	6
K	15-19	3	6-7	5-6	5-6	7-9
T	20+	4+	8+	7+	7+	10+

Atomic Absorption

	Fe	Ag	Al	Cr	Cu	Mg
A	0-5	0	0-2	0-2	0-2	0-3
N	6	1	3	3	3	4
K	7-8	2	4	4	4	5
T	9+	3+	5+	5+	5+	6+

Codes:

A – Continue routine sampling.

N – Do not change oil, submit redtagged sample after each flying day.

K – Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded.

T – Ground unit, examine for suspected discrepancy. Advise laboratory of findings.

J57-13/23/55
(F-101/F-102)

Copper is the most significant and critical wearmetal. When copper is detected by itself in any amount, maintain close surveillance. Increasing trends in copper are usually indicative of problem in the Nos. 2, 4, and/or No. 5 bearing areas. In cases of advanced wear, copper may be accompanied by increases in iron. Whenever Fe increases in combination with an increase in Cu, inspect for excessive Nos. 2, 4, and/or No. 5 bearing wear. Silver may also be detected in advanced bearing wear. Increases in magnesium usually indicate discrepancy in accessory gearbox (OPAH). When Mg is accompanied by an increase in Fe, the discrepancy is usually in the OPAH bearing area. Increase in aluminum, by itself or when accompanied by a small increase in iron and sometimes Cu, usually indicates discrepancy with the main lube pump or scavenge pump. Increases in iron alone may indicate defect in EMGB (F-102).

Fe	Main bearing balls/rollers, races, and seals Gearbox gears
Fe Al	No. 6 scavenge oil pump Gearbox oil pump
Fe Al Ag Cu & Si Sn	Nos. 4, 4½ and 5 scavenge oil pump
Fe Ag	Nos. 2½ and 3 bearing cages (2½ bearing applicable to -55 engine only)
Fe Ag Cu & Si Sn	Gearbox bearings
Fe Mg	No. 1 scavenge oil pump
Ag Cu & Si Sn	Nos. 1, 2, 4, 4½, 5, and 6 bearing cages
Al Mg	Gearbox housing and adapter

J57-19/43/59
(B-52/C-135)

A/E 35 U-1

	Fe	Ag	Al	Cr	Cu	Mg	Ti
A	0-15	0-2	0-4	0-3	0-3	0-8	0-4
N	16-19	3	5	4	4	9-11	5-6
K	20-24	4	6-7	5-6	5-6	12-14	7-8
T	25+	5+	8+	7+	7+	15+	9+

A/E 35 U-3

	Fe	Ag	Al	Cr	Cu	Mg	Ti
A	0-19	0-3	0-5	0-5	0-5	0-5	0-5
N	20-24	4	6-7	6-7	6-7	6-7	6-7
K	25-29	5-6	8-9	8-9	8-9	8-9	8-9
T	30+	7+	10+	10+	10+	10+	10+

Atomic Absorption

	Fe	Ag	Al	Cr	Cu	Mg	Ti
A	0-7	0-1	0-2	0-2	0-2	0-5	0-2
N	8-9	2	3	3	3	6-7	3
K	10-11	3	4	4	4	8-9	4
T	12+	4+	5+	5+	5+	10+	5+

Codes:

A – Continue routine sampling.

N – Do not change oil, submit redtagged sample after each flying day.

K – Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded.

T – Ground unit, examine for suspected discrepancy. Advise laboratory of findings.

J57-19/43/59
(B-52/C-135)

Copper is the most significant and critical wearmetal. When copper is detected by itself in any amount, maintain close surveillance. Increasing trends in copper are usually indicative of problem in the Nos. 2, 4, and/or No. 5 bearing. In cases of advanced wear, copper may be accompanied by increases in iron. Whenever Fe increases in combination with an increase in Cu, inspect for excessive Nos. 2, 4 and/or No. 5 bearing wear. Silver may also be detected in advanced bearing wear. Increases in magnesium usually indicate discrepancy in accessory gearbox (OPAH). When Mg is accompanied by an increase in Fe, the discrepancy is usually in the OPAH bearing area. When aluminum increases to "T" value or is accompanied by a small increase in iron and, sometimes, Cu, the discrepancy is usually with the main lube pump or scavenge pump. Increases in Cr may indicate excessive wear or failure of carbon seal. Increase in Ti indicates Nos. 1, 2, 2½ and/or 3 bearing hub wear in J57-43 engine.

Fe	Main bearing balls/rollers, races, and seals Gearbox gears
Fe Al	No. 6 scavenge oil pump Gearbox oil pump
Fe Al Ag Cu & Si Sn	Nos. 4, 4½ and 5 scavenge oil pump
Fe Ag	Nos. 2½ and 3 bearing cages (2½ bearing applicable to -43 and -59 engines only)
Fe Ag Cu	Gearbox governor and tach drive bearings (-19 and -29 engines)
Fe Ag Cu & Si Sn	Gearbox bearings
Fe Mg	No. 1 scavenge oil pump
Ag Cu & Si Sn	Nos. 1, 2, 4, 4½, 5 and 6 bearing cages
Al Mg	Gearbox housing and adapter

J57-21
(F-100)

A/E 35 U-1

	Fe	Ag	Al	Cr	Cu	Mg
A	0-14	0-2	0-4	0-3	0-5	0-5
K	15-19	3	5-6	4-5	6-7	6-7
T	20+	4+	7+	6+	8+	8+

A/E 35 U-3

	Fe	Ag	Al	Cr	Cu	Mg
A	0-20	0-2	0-5	0-4	0-6	0-6
K	21-26	3	6-7	5-6	7-9	7-9
T	27+	4+	8+	7+	10+	10+

Atomic Absorption

	Fe	Ag	Al	Cr	Cu	Mg
A	0-6	0-1	0-2	0-2	0-2	0-3
K	7-8	2	3-4	3-4	3-4	4-5
T	9+	3+	5+	5+	5+	6+

Codes:

A – Continue routine sampling.

K – Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded.

T – Ground unit, examine for suspected discrepancy. Advise laboratory of findings.

J57-21
(F-100)

Copper is the most significant and critical wearmetal. When copper is detected by itself in any amount, maintain close surveillance. Increasing trends in copper are usually indicative of problem in the Nos. 2, 4, and/or 5 bearing areas. In cases of advanced wear, copper may be accompanied by increases in iron. Whenever Fe increases in combination with an increase in Cu, inspect for excessive Nos. 2, 4, and/or No. 5 bearing wear. Silver may also be detected in advanced bearing wear. Increases in magnesium usually indicate discrepancy in accessory gearbox (OPAH). When Mg is accompanied by an increase in Fe, the discrepancy is usually in the OPAH bearing area. Increase in aluminum, by itself or when accompanied by a small increase in iron and sometimes Cu, usually indicates discrepancy with the main lube pump or scavenge pump.

Fe	Main bearing balls/rollers, races, and seals Gearbox gears
Fe Al	No. 6 scavenge oil pump Gearbox oil pump
Fe Al Ag Cu & Si Sn	Nos. 4, 4½ and 5 scavenge oil pump
Fe Ag	No. 3 bearing cage
Fe Ag Cu & Si Sn	Gearbox bearings
Fe Mg	No. 1 scavenge oil pump
Ag Cu & Si Sn	Nos. 1, 2, 4, 4½, 5, and 6 bearing cages
Al Mg	Gearbox housing and adapter

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REVISION OF TECHNICAL MANUAL SPECTROMETRIC OIL ANALYSIS PROGRAM--ETC(U)
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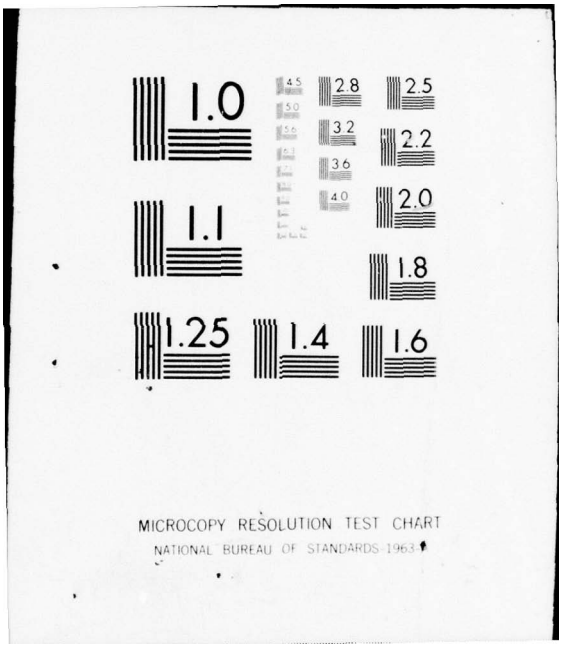
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NATIONAL BUREAU OF STANDARDS-1963-A

J60-3
(T-39)

A/E 35 U-1

	Fe	Ag	Al	Cr	Cu	Mg
A	0-19	0-4	0-5	0-4	0-7	0-10
N	20-23	5	6-7	5	8-9	11-14
K	24-29	6-7	8-9	6-7	10-12	15-19
T	30+	8+	10+	8+	13+	20+

A/E 35 U-3

	Fe	Ag	Al	Cr	Cu	Mg
A	0-23	0-5	0-7	0-5	0-9	0-10
N	24-27	6	8	6	10-11	11-14
K	28-34	7-8	9-11	7-8	12-14	15-19
T	35+	9+	12+	9+	15+	20+

Atomic Absorption

	Fe	Ag	Al	Cr	Cu	Mg
A	0-10	0-2	0-4	0-2	0-5	0-2
N	11-12	3	5	3	6-7	3
K	13-15	4	6-7	4	8-9	4-5
T	16+	5+	8+	5+	10+	6+

Codes:

A – Continue routine sampling.

N – Do not change oil, submit redtagged sample after each flying day.

K – Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded.

T – *Ground unit, examine for suspected discrepancy.* Advise laboratory of findings.

J60-3
(T-39)

When Fe increases in combination with an increase in Mg, the discrepancy is usually with the accessory gear case. When Fe increases in combination with an increase in Cu, the discrepancy may be a main shaft bearing, usually No. 3. High Fe, Cu, and Mg in combination usually indicate discrepancy with the tower shaft bearing. Increases in Mg by itself indicate defect in accessory gear case. Fuel contamination of oil indicates rupture of fuel oil cooler.

Fe	Main bearing balls/rollers and races Gearbox gears
Fe Al	Pressure and scavenge oil pump
Fe Ag Cu & Si Sn	Gearbox bearings
Ag Cu & Si Sn	Main bearing cages
Al Mg	Gearbox housing and adapters

J69-25
(T-37)

A/E 35 U-1

	Fe	Ag	Al	Cr	Cu	Mg
A	0-19	0-3	0-4	0-3	0-9	0-6
N	20-29	4-5	5-7	4-6	10	7-10
K	30-34	6-7	8-9	7-9	11-12	11-12
T	35+	8+	10+	10+	13+	13+

A/E 35 U-3

	Fe	Ag	Al	Cr	Cu	Mg
A	0-19	0-4	0-7	0-6	0-8	0-7
N	20-29	5-7	8-11	7-10	9	8-11
K	30-34	8-9	12-14	11-14	10	12-14
T	35+	10+	15+	15+	11+	15+

Atomic Absorption

	Fe	Ag	Al	Cr	Cu	Mg
A	0-14	0-2	0-3	0-3	0-5	0-5
N	15-17	3	4	4	6-7	6-7
K	18-21	4	5	5	8-9	8-9
T	22+	5+	6+	6+	10+	10+

Codes:

A – Continue routine sampling.

N – Do not change oil, submit redtagged sample after each flying day.

K – Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded.

T – Ground unit, examine for suspected discrepancy. Advise laboratory of findings.

J69-25
(T-37)

Fuel contamination of the engine oil is a common occurrence and is allowable within limits specified in T.O. 2J-J69-46. Fuel contamination of the oil will be reported to responsible activity when detected. Fe is principal wearmetal. Gradual increases in Fe near or to the "T" value over a long period of time (several hundred flying hours) is sometimes indicative of rotational movement of the No. 2 bearing. This rotational movement, or creep, characteristic is normal and is a design feature of the No. 2 bearing. Rapid increases in Fe are sometimes indicative of accessory drive gearshaft nut backing off because of a sheared tang on the nut lock. Rapid increases in Al, to or exceeding "T" value, can sometimes be attributed to improper stack up of the engine resulting in rub of the No. 2 bearing labyrinth seal against the turbine shaft. When Cr approaches the "T" value, it is a possible indication of wear in the No. 2 bearing housing, or front and rear turbine shaft. Increases in Ag are indicative of bearing wear and are usually in combination with high Fe and Cu. Increases in Cu and Mg individually, or together, are an indication of problem in the accessory case section.

Fe	Main bearing balls/rollers and races Starter generator and accessory drive gears Accessory case gears
Fe Al & Cr	Accessory oil pump
Fe Ag Cu & Sn	Accessory case bearings
Cu Sn	Starter generator and accessory drive bearing cages
Cu & Sn Ag	Main bearing cages
Al Mg	Accessory case housing and adapters

A/E 35 U-1

	Fe	Ag	Al	Cr	Cu	Mg	Ti
A	0-23	0-1	0-4	0-3	0-5	0-11	0-5
N	24-25	2	5	4	6	12	6
K	26-29	3	6	5	7-8	13-14	7-8
T	30+	4+	7+	6+	9+	15+	9+

A/E 35 U-3

	Fe	Ag	Al	Cr	Cu	Mg	Ti
A	0-22	0-2	0-5	0-4	0-6	0-13	0-6
N	23-24	3	6	5	7	14-15	7
K	25-27	4	7	6	8-9	16-17	8-9
T	28+	5+	8+	7+	10+	18+	10+

Atomic Absorption

	Fe	Ag	Al	Cr	Cu	Mg	Ti
A	0-6	0	0	0-1	0-3	0-4	0-1
N	7-8	1	1	2	4	5-6	2
K	9-11	2	2-3	3-4	5-6	7-9	3-4
T	12+	3+	4+	5+	7+	10+	5+

Codes:

A – Continue routine sampling.

N – Do not change oil, submit redtagged sample after each flying day.

K – Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded.

T – Ground unit, examine for suspected discrepancy. Advise laboratory of findings.

J75-17
(F-106)

High Fe or Fe in combination with Cu usually indicate bearing trouble, particularly Nos. 4 or 5 bearings. Increases in Mg in combination with Al indicate possible discrepancy due to fretting of bearing liner in the main gearbox. High Mg and Fe may also indicate defective oil pump. Titanium (Ti) is a significant wearmetal. Increases in Ti are indicative of the spacer between Nos. 2, 2½ and 3 bearings turning on the shaft. High Fe together with high Ti indicate discrepancy in the Nos. 2, 2½ and No. 3 bearing area.

Fe	Main bearing balls/rollers, races, seals and housing Front accessory drive gears Main accessory drive gears and housing Main gearbox gears
Fe Al	Front accessory drive oil pump Main gearbox oil pump
Fe Ag	No. 3 bearing cages Main accessory drive bearings
Fe Ag Cu & Si Sn	Main gearbox bearings
Ag Cu & Si Sn	Nos. 1, 2, 2½, 4, 4½, 5 and 6 bearing cages
Mg	Front accessory drive and main gearbox housing
Ti	No. 2 hub shaft between Nos. 2, 2½ and 3 main bearing

J75-19
(F-105)

A/E 35 U-1

	Fe	Ag	Al	Cr	Cu	Mg	Ti
A	0-25	0-2	0-5	0-4	0-6	0-12	0-6
K	26-29	3	6	5	7-8	13-14	7-8
T	30+	4+	7+	6+	9+	15+	9+

A/E 35 U-3

	Fe	Ag	Al	Cr	Cu	Mg	Ti
A	0-24	0-3	0-6	0-5	0-7	0-15	0-7
K	25-27	4	7	6	8-9	16-17	8-9
T	28+	5+	8+	7+	10+	18+	10+

Atomic Absorption

	Fe	Ag	Al	Cr	Cu	Mg	Ti
A	0-8	0-1	0-1	0-2	0-4	0-6	0-2
K	9-11	2	2-3	3-4	5-6	7-9	3-4
T	12+	3+	4+	5+	7+	10+	5+

Codes:

A – Continue routine sampling.

K – Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded.

T – Ground unit, examine for suspected discrepancy. Advise laboratory of findings.

J75-19
(F-105)

High Fe or Fe in combination with Cu usually indicate bearing trouble, particularly Nos. 4 or 5 bearings. Increases in Mg in combination with Al indicate possible discrepancy due to fretting of bearing liner in the main gearbox. High Mg and Fe may also indicate defective oil pump. Titanium (Ti) is a significant wearmetal. Increases in Ti are indicative of the spacer between Nos. 2, 2½ and 3 bearings turning on the shaft. High Fe together with high Ti indicate discrepancy in the Nos. 2, 2½, and No. 3 bearing area.

Fe	Main bearing balls/rollers, races, seals and housing Front accessory drive gears Main accessory drive gears and housing Main gearbox gears
Fe Al	Front accessory drive oil pump Main gearbox oil pump
Fe Ag	No. 3 bearing cages Main accessory drive bearings
Fe Ag Cu & Si Sn	Main gearbox bearings
Ag Cu & Si Sn	Nos. 1, 2, 2½, 4, 4½, 5 and 6 bearing cages
Mg	Front accessory drive and main gearbox housing
Ti	No. 2 hub shaft between Nos. 2, 2½ and 3 main bearing

J79-11
(F-104)

A/E 35 U-1

	Fe	Ag	Al	Cr	Cu	Mg
A	0-25	0-1	0-3	0-3	0-10	0-10
N	26-29	2	4	4	11-12	11-12
K	30-34	3	5	5	13-14	13-14
T	35+	4+	6+	6+	15+	15+

A/E 35 U-3

	Fe	Ag	Al	Cr	Cu	Mg
A	0-29	0-1	0-5	0-5	0-12	0-14
N	30-34	2	6	6	13-15	15-16
K	35-39	3	7	7	16-17	17-19
T	40+	4+	8+	8+	18+	20+

Atomic Absorption

	Fe	Ag	Al	Cr	Cu	Mg
A	0-18	0	0-2	0-1	0-6	0-6
N	19-21	1	3	2	7	7
K	22-24	2	4	3	8-9	8-9
T	25+	3+	5+	4+	10+	10+

Codes:

A – Continue routine sampling.

N – Do not change oil, submit redtagged sample after each flying day.

K – Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded.

T – Ground unit, examine for suspected discrepancy. Advise laboratory of findings.

J79-11
(F-104)

A gradual increase of iron by itself (negative sump oil system) is usually indicative of leak in fuel pump seal due to worn pump drive spline. High iron (all engines) may result from bearing race rotation in the gearbox bearing housing. Any increase in Fe and Mg in combination usually indicates a discrepancy with the inlet or transfer gearbox spanner nuts. Increases in copper by itself are usually indicative of a worn oil pump, scavenge pump, primary nozzle, or emergency nozzle pump.

[Fe] & Ni	Gearbox bearing housings
[Fe] & CR	No. 2 bearing balls and races Afterburner fuel pump gears and bearings
[Fe] & Cr Ni	Main bearing roller races, lube jets, carbon seal runners and seal races Gearbox gears, shafts and splines
[Fe] & Cr Cu Ni	Accessory nozzle actuators
[Fe Cu] & Al Si	Main lube pump and three scavenge pumps
[Fe Cu] & Cr Ag Ni	Gearbox bearings
[Fe Cu] & Al Sn Pb Ni Si	Accessory emergency nozzle pump
[Fe Cu Ag] & Pb Ni Si Al Cr Sn	Accessory primary hydraulic pump
[Cu] & Fe Ag Si	Main bearing cages
[Mg Al]	Gearbox castings

A/E 35 U-1

	Fe	Ag	Al	Cr	Cu	Mg
A	0-14	0-2	0-3	0-4	0-10	0-9
D	15-17	3	4	5	11	10-11
K	18-22	4	5	6-7	12-14	12-14
T	23+	5+	6+	8+	15+	15+

A/E 35 U-3

	Fe	Ag	Al	Cr	Cu	Mg
A	0-18	0-2	0-4	0-5	0-8	0-9
D	19-22	3	5	6	9	10-11
K	23-27	4-5	6-7	7-8	10-11	12-13
T	28+	6+	8+	9+	12+	14+

Atomic Absorption

	Fe	Ag	Al	Cr	Cu	Mg
A	0-10	0	0-1	0-3	0-3	0-5
D	11-12	1	2	4	4	6-7
K	13-15	2	3	5	5	8-9
T	16+	3+	4+	6+	6+	10+

Codes:

A – Continue routine sampling.

D – *Do not change oil, submit redtagged sample after each flight.*

K – Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded.

T – Ground unit, examine for suspected discrepancy. Advise laboratory of findings.

J79-15/17
(F-4)

Caution must be exercised when evaluating this system due to the common oil supply of engine and CSD. When Fe increases by itself or in combination with Cu, recommend transfer gearbox starter drive area be checked for loose nut on drive or for broken carbon seal. Also recommend inspection of the front of transfer gearbox for same problem and inspection of filters including CSD inlet filter. Recommend backlash check be performed. When Cu increases in combination with Fe, but copper is higher, the problem will usually be in the CSD. High magnesium is usually indicative of discrepancy in the gearbox. Any increase in Ag is usually indicative of incipient No. 2 bearing failure and will be accompanied with high Fe with or without increases in Cu.

[Fe] & Ni	Main bearing housings
[Fe] & Cr	Afterburner fuel pump gears and bearings No. 2 bearings, balls and races
[Fe] & Cr Ni	No. 1 bearing rollers, races and carbon seal runners Gearbox gears, shafts and splines
[Fe] & Cr Al or Ni	No. 3 bearing rollers and races
[Fe] & Cr Cu Ni	Accessory variable nozzle actuator
[Fe Cu] & Al Si	Accessory main lube and hydraulic pump
[Fe Cu] & Al Ni	Accessory scavenge pumps
[Fe Cu] & Ag Cr Si	Gearbox bearings
[Fe Cu Mg] & Al	Constant speed drive
[Fe Cu Ag*] & Al Cr Sn Pb Ni Si	Accessory variable nozzle pump (*Ag in 1P, 1M and 1N pumps)
[Fe Cu Al Mg] & Cr Ni	Variable nozzle control valve
[Cu] & Ag Fe Si	Main bearing cages
[Al Mg]	Gearbox castings
[Cr] & Fe Ni	Main bearing seal races

J85-5/17
(T-38/A-37)

A/E 35 U-1

	Fe	Ag	Al	Cr	Cu	Mg
A	0-30	0-3	0-2	0-4	0-4	0-9
N	31-35	4	3	5	5	10-12
K	36-39	5	4	6	6-7	13-15
T	40+	6+	5+	7+	8+	16+

A/E 35 U-3

	Fe	Ag	Al	Cr	Cu	Mg
A	0-30	0-4	0-3	0-5	0-4	0-6
N	31-35	5	4	6-7	5	7-8
K	36-39	6	5	8	6-7	9-10
T	40+	7+	6+	9+	8+	11+

Atomic Absorption

	Fe	Ag	Al	Cr	Cu	Mg
A	0-14	0-1	0	0-2	0-2	0-2
N	15-16	2	1	3	3	3
K	17-21	3	2	4	4	4
T	22+	4+	3+	5+	5+	5+

Codes:

A – Continue routine sampling.

N – Do not change oil, submit redtagged sample after each flying day.

K – Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded.

T – Ground unit, examine for suspected discrepancy. Advise laboratory of findings.

No. 2 main bearing is a major problem area detectable by SOAP. These failures usually occur rapidly. Maintain close surveillance even when small increases in Fe are noted. High iron and copper (with/without silver) indicate main or accessory bearing defect. Suspect first, No. 3 and No. 2 main bearings; next, Axis "E" accessory bearing. High silver alone indicates JP-4 contamination of lube system; recommend inspection of fuel oil cooler and/or fuel pump.

[Fe]	Accessory lube lines
[Fe] & Ni	No. 1 bearing races
[Fe] & Cr	No. 1 bearing rollers and front frame casing Nos. 2 and 3 bearing support Accessory drive gearbox and PTO bearing balls/rollers and races Accessory drive gearbox seal and bearing housings
[Fe] & Cr Ni	Main bearing carbon seal runners No. 1 bearing compressor rotor front shaft No. 2 bearing locknut and compressor driveshaft No. 3 bearing locknut and turbine wheel shaft PTO radial driveshaft, bevel gears, bearing housing, axial bearing support and retainer Accessory lube and scavenge pump spur gear, lube filter and oil cooler valve Accessory drive gearbox shaft and bevel gears
[Fe] & Cr Ni Si	Accessory drive gearbox gear locknut
[Fe] & Cr Ni Mg	PTO and No. 2 bearing retainer Accessory drive gearbox spanner nuts
[Fe] & Cr Al	Nos. 2 and 3 bearing balls/rollers and races Accessory drive gearbox seal mating rings Accessory lube and scavenge pump rotors, liners and blades
[Al]	Accessory oil cooler housing, oil pressure transducer and oil tank
[Al] & Mg Si	Accessory filter bypass relief valve housing
[Al] & Cu Mg Si	Accessory lube and scavenge pump housing
[Cu] & Al Fe Pb Si	Accessory lube and scavenge pump bearings
[Cu Si] & Fe Ag	Main and PTO bearing cages Accessory drive gearbox bearing cages

TF30 - All Series
(F-111/FB-111)

A/E 35 U-1

	Fe	Ag	Al	Cr	Cu	Mg	Ni	Ti
A	0-7	0-2	0-4	0-3	0-3	0-6	0-13	0-8
K	8-9	3	5-6	4	4	7-8	14-17	9-11
T	10+	4+	7+	5+	5+	9+	18+	12+

A/E 35 U-3

	Fe	Ag	Al	Cr	Cu	Mg	Ni	Ti
A	0-15	0-2	0-4	0-3	0-3	0-5	0-15	0-9
K	16-23	3-4	5-7	4-5	4-5	6-9	16-24	10-15
T	24+	5+	8+	6+	6+	10+	25+	16+

Atomic Absorption

	Fe	Ag	Al	Cr	Cu	Mg	Ni	Ti
A	0-5	0-1	0-2	0-1	0-2	0-3	0-8	0-5
K	6-7	2	3-4	2	3	4-5	9-11	6-7
T	8+	3+	5+	3+	4+	6+	12+	8+

Codes:

A – Continue routine sampling.

K – Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded.

T – Ground unit, examine for suspected discrepancy. Advise laboratory of findings.

TF30 - All Series
(F-111/FB-111)

Iron is the primary wearmetal. Trouble is usually in the No. 4 or No. 6 bearing. If a combination of Fe and Ti trend develops and Ti increases at higher rate than Fe, trouble is usually in the bearing housing. Nickel is also a significant wearmetal. Increases in Fe and Ni in combination usually indicate shearing of rivet pins holding collar on the No. 5 bearing seal.

Fe	Main bearing balls/rollers, races and seal plates No. 6 bearing pump gears Accessory drive shaft Gearbox gears, shafts and splines
Fe Cr	Nos. 2 and 3 bearing seal rings
Fe Ag	Main bearing cages Accessory drive and gearbox bearings
Fe Al	Accessory drive oil pumps and coolers
Al	No. 4 bearing pump housing
Al Mg	Gearbox castings
Mg	No. 1 bearing housing Accessory drive housing
Ag Cu & Sn Si	No. 1 bearing accessory drive bearing cages No. 4 bearing shaftgear bearings and cages
Ni	Nos. 4½ and 5 bearing seal liner
Ti	Nos. 2 and 3 bearing support assemblies No. 3 bearing sleeves

TF33 - All Series
(B-52/C-135/C-141)

A/E 35 U-1

	Fe	Ag	Al	Cr	Cu	Mg
A	0-7	0	0-1	0-1	0-1	0-3
N	8-12	1	2	2-3	2-3	4-6
K	13-19	2-3	3-5	4-6	4-6	7-11
T	20+	4+	6+	7+	7+	12+

A/E 35 U-3

	Fe	Ag	Al	Cr	Cu	Mg
A	0-7	0-1	0-1	0-2	0-2	0-5
N	8-12	2	2-3	3	3	6-9
K	13-18	3-4	4-5	4-6	4-6	10-14
T	19+	5+	6+	7+	7+	15+

Atomic Absorption

	Fe	Ag	Al	Cr	Cu	Mg
A	0-4	0	0-1	0	0	0-2
N	5-7	1	2	1	1	3-4
K	8-11	2	3-4	2-3	2-3	5-7
T	12+	3+	5+	4+	4+	8+

Codes:

A – Continue routine sampling.

N – Do not change oil, submit redtagged sample after each flying day.

K – Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded.

T – Ground unit, examine for suspected discrepancy. Advise laboratory of findings.

TF33 - All Series
(B-52/C-135/C-141)

Sudden increase in magnesium indicates discrepancy in the accessory gearbox.

Fe	Main bearing balls/rollers, races, seals and housing Front and main accessory drive gears Main gearbox gears
Fe Al	Front accessory drive and main gearbox oil pumps
Fe Ag	Main accessory drive bearings Nos. 2, 3, 4, 4½, 5 and 6 bearing cages (-7 engine) No. 2½ bearing cages (-3, -5, -9, -11 engines)
Fe Ag Cu & Si Sn	Main gearbox bearings
Ag Cu & Si Sn	Nos. 1 and 2½ bearing cages (-7 engine) Nos. 1, 2, 3, 4, 4½, 5 and 6 bearing cages (-3, -5, -9, -11 engines)
Mg	Main accessory drive housing

TF39-1
(C-5)

A/E 35 U-1

	Fe	Ag	Al	Cr	Cu	Mg
A	0-11	0	0-3	0	0-5	0-9
N	12-18	1	4-5	1	6-8	10-15
K	19-29	2-3	6-9	2-3	9-14	16-24
T	30+	4+	10+	4+	15+	25+

A/E 35 U-3

	Fe	Ag	Al	Cr	Cu	Mg
A	0-13	0-1	0-4	0-1	0-7	0-11
N	14-23	2	5-7	2	8-12	12-19
K	24-34	3-4	8-11	3-4	13-19	20-29
T	35+	5+	12+	5+	20+	30+

Atomic Absorption

	Fe	Ag	Al	Cr	Cu	Mg
A	0-7	0	0-1	0	0-3	0-5
N	8-12	1	2-3	1	4-5	6-9
K	13-19	2	4-6	2	6-9	10-14
T	20+	3+	7+	3+	10+	15+

Codes:

A – Continue routine sampling.

N – Do not change oil, submit redtagged sample after each flying day.

K – Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded.

T – Ground unit, examine for suspected discrepancy. Advise laboratory of findings.

TF39-1
(C-5)

[Fe]	Inlet and transfer gearbox bearing housings and retainers
[Fe] & Ag	Inlet and transfer gearbox shafts
[Fe] & Cr	Inlet and transfer gearbox bearings and races Nos. 1 and 3 main bearing rollers and races
[Fe] & Ni	No. 4B bearing housing spanner nut
[Fe] & Mn	Lube and scavenge pump shaft and elements
[Fe] & Ag Ni	No. 1 main bearing cages
[Fe] & Cr Ni	Inlet and transfer gearbox gears
[Fe] & Cr Cu Ni	Nos. 4, 6, and 7 main bearing rotating oil seals
[Fe] & Ag Cr Cu Ni	Nos. 4, 5, 6, and 7 main bearing stationary air and oil seal
[Fe] & Cr Mo V	Nos. 2, 4, 5, 6, and 7 main bearing rollers and races No. 5 main bearing fan shaft
[Fe] & Ni Co Mo	No. 2 main bearing fan shaft
[Al] & Mg	Lube and scavenge pump air/oil separator seal
[Al] & Si	Forward scavenge pump housing
[Al] & Cu Si	Lube and scavenge pump cover
[Cu] & Fe Ag Si	No. 3 main bearing cages
[Cu] & Fe Ag Si Zn	Nos. 2, 4, 5, 6, and 7 main bearing cages Inlet and transfer gearbox cages
[Cu] & Al Zn Mn	Lube and scavenge pump bearings
[Mg] & Zn	Transfer gearbox housing
[Ti] & Al Sn	No. 2 main bearing fan frame
[Ti] & Al V	No. 1 main bearing fan stub shaft and rotating air and oil seal No. 3 main bearing stage two-rotor disk (rotating oil seal) No. 5 main bearing HP turbine rear shaft (rotating oil seal)

TF41-1
(A-7)

A/E 35 U-1

	Fe	Ag	Al	Cr	Cu	Mg
A	0-11	0-2	0-2	0-2	0-11	0-3
K	12-15	3	3-4	3	12-14	4-5
T	16+	4+	5+	4+	15+	6+

A/E 35 U-3

	Fe	Ag	Al	Cr	Cu	Mg
A	0-7	0-2	0-1	0-2	0-11	0-4
K	8-9	3	2	3	12-13	5-6
T	10+	4+	3+	4+	14+	7+

Atomic Absorption

	Fe	Ag	Al	Cr	Cu	Mg
A	0-7	0-1	0-1	0-1	0-4	0-1
K	8-9	2	2	2	5-6	2
T	10+	3+	3+	3+	7+	3+

Codes:

A – Continue routine sampling.

K – Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded.

T – Ground unit, examine for suspected discrepancy. Advise laboratory of findings.

TF41-1
(A-7)

NOTE: Caution must be exercised when evaluating this engine due to high oil consumption and small oil tank capacity. Use of decision tables alone as a basis for evaluation may be misleading. Trend analysis must be utiiized to successfully evaluate this engine. It is also recommended that test results be plotted on graphs to assist in evaluations. A developing trend may be indicated with increases of one or two ppm in one or more elements. If a developing trend is suspected by small increases of wearmetal(s), one or two ppm, maintain close surveillance. DO NOT request "drain and flush." Use the next sample to confirm past results. If the suspected developing trend is 3 ppm or greater in one or more elements, immediately notify maintenance NOT to add or change oil and request check sample after 30 minutes ground run. If a trend continues to develop, in either situation, notify propulsion branch chief and recommend positive maintenance action be taken.

Increases in copper by itself may indicate defective bearing. Increases in copper accompanied by increases in iron may also indicate abnormal bearing wear and/or seal ring wear. Increases in chromium by itself in any amount may indicate rotation of No. 6 bearing outer race in housing. Increases in Cr accompanied by iron may indicate piston ring seal wear and could result in excessive oil consumption. Increases in Al may indicate fretting of internal gearbox cover and/or oil pump. Increases in Mg may indicate abnormal wear in high speed gearbox.

Fe	Internal gearbox housing and gears
Fe & Cu	Internal gearbox bearings
Fe & Ni	No. 7 bearing oil seal sleeve No. 3 bearing area gears Oil pump shafting and gears External gearbox gears and shafts
Fe & Cr	Nos. 1, 2 and 3 bearing balls/rollers and races Nos. 1 and 2 bearing seal rings (Dynamic) No. 2 bearing ring seals (Static) Nos. 4 and 5 bearing rear oil seal and sleeve No. 6 bearing seal liner, ring and housing No. 7 bearing oil seal ring and housing
Fe & W	No. 6 bearing sleeve No. 7 bearing rollers and races
Fe & Cr W	Nos. 4 and 5 bearing balls and races
Fe & Cr W V	No. 6 bearing outer race rollers
Fe & Cr V Mo	Nos. 3, 4 and 5 bearing shaft
Al	No. 1 bearing front and rear static air seals No. 2 bearing and oil pump housing
Ag & Cu Sn	Nos. 4 and 5 bearing front oil seal No. 3 bearing oil seal
Cu & Ni Si	Main bearing cages or retainers Oil pump bushings External gearbox bearing cages

T53-11/13
(H-43/H-1)

A/E 35 U-1

	Fe	Ag	Al	Cr	Cu	Mg
A	0-11	0-3	0-7	0-3	0-5	0-5
N	12-13	4	8	4	6-7	6-7
K	14-17	5-6	9-11	5-6	8-9	8-9
T	18+	7+	12+	7+	10+	10+

A/E 35 U-3

	Fe	Ag	Al	Cr	Cu	Mg
A	0-12	0-4	0-5	0-4	0-7	0-7
N	13-15	5	6-7	5	8	8
K	16-19	6-7	8-9	6-7	9-11	9-11
T	20+	8+	10+	8+	12+	12+

Atomic Absorption

	Fe	Ag	Al	Cr	Cu	Mg
A	0-7	0-2	0-2	0-2	0-2	0-2
N	8	3	3	3	3	3
K	9-11	4	4	4	4-5	4-5
T	12+	5+	5+	5+	6+	6+

Codes:

A – Continue routine sampling.

N – Do not change oil, submit redtagged sample after each flying day.

K – Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded.

T – Ground unit, examine for suspected discrepancy. Advise laboratory of findings.

Iron usually indicates torque meter discrepancy.

T56-7/9
(C-130)

A/E 35 U-1

	Fe	Ag	Al	Cr	Cu	Mg
A	0-16	0	0-3	0-1	0-10	0-8
N	17-19	1	4	2	11	9-10
K	20-24	2	5-6	3	12-13	11
T	25+	3+	7+	4+	14+	12+

A/E 35 U-3

	Fe	Ag	Al	Cr	Cu	Mg
A	0-20	0	0-3	0-1	0-9	0-21
N	21-24	1	4	2	10	22-24
K	25-29	2	5-6	3	11	25-26
T	30+	3+	7+	4+	12+	27+

Atomic Absorption

	Fe	Ag	Al	Cr	Cu	Mg
A	0-13	0	0-3	0-1	0-4	0-6
N	14	1	4	2	5	7
K	15	2	5	3	6-7	8
T	16+	3+	6+	4+	8+	9+

Codes:

A – Continue routine sampling.

N – Do not change oil, submit redtagged sample after each flying day.

K – Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded.

T – Ground unit, examine for suspected discrepancy. Advise laboratory of findings.

T56-7/9
(C-130)

Caution must be exercised when evaluating this system since the power section and reduction gearbox are lubricated with the same oil supply. Major problem area detected by SOAP is the reduction gearbox lube pump. High Cu by itself usually results from newly depot-overhauled pumps due to flaking or wearing of bronze spray coating in pump cavities. Reduction gearbox lube pump failures are usually indicated when Fe, Cu and Mg increase in combination at or near the same rate. When Fe increase is more than Cu increase, accompanied by moderate increase in Mg and small amount of Cr and Ag, discrepancy is usually with the reduction gearbox pinion bearing. When increase in Fe and Mg occur, accompanied by moderate increase in Cu with small amount of Cr and Ag, the discrepancy is usually in one of three components: power section side gear bearing, accessory case bearing, or reduction gearbox oil pump drive gear bearing. A significant increase in Fe in absence of other wearmetals may indicate discrepancy in reduction gear train and/or rear turbine scavenge pump assembly. Bronze metalizing repair procedure on oil pumps is discontinued and will reduce copper content.

Fe	Main bearing balls/rollers and races Reduction gear assembly gears Accessory drive gears, shafts and splines
Fe Cu & Si	Accessory diffuser scavenge pump
Fe Cu & Si Mg	Accessory turbine scavenge pump
Fe Mg	Accessory drive housing
Mg	Reduction gear assembly housing
Cu Mg	Reduction gear assembly oil pump
Cu Ag & Fe Si	Main bearing cages Reduction gear assembly bearings

T58-1/5
(H-3)

A/E 35 U-1

	Fe	Ag	Al	Cr	Cu	Mg
A	0-15	0-1	0-4	0-1	0-8	0-5
N	16-19	2	5	2	9-10	6-7
K	20-24	3	6-7	3	11-13	8-9
T	25+	4+	8+	4+	14+	10+

A/E 35 U-3

	Fe	Ag	Al	Cr	Cu	Mg
A	0-19	0-2	0-5	0-2	0-9	0-7
N	20-23	3	6-7	3	10-11	8
K	24-29	4	8-9	4	12-15	9-11
T	30+	5+	10+	5+	16+	12+

Atomic Absorption

	Fe	Ag	Al	Cr	Cu	Mg
A	0-9	0	0-2	0	0-4	0-2
N	10-11	1	3	1	5	3
K	12-14	2	4	2	6-7	4-5
T	15+	3+	5+	3+	8+	6+

Codes:

A – Continue routine sampling.

N – Do not change oil, submit redtagged sample after each flying day.

K – Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded.

T – Ground unit, examine for suspected discrepancy. Advise laboratory of findings.

T58-1/5
(H-3)

[Fe] & Cr	Accessory bearing outer race No. 3 bearing outer race No. 5 bearing outer race (-5 & -8 engines)
[Fe] & Cr Ni	Nos. 2 and 4 bearing outer race (-8 engine) No. 4 bearing outer race (-5 engine) Nos. 2, 4 and 5 bearing outer race (-10 engine)
[Fe Al] & Cr Ni	Power turbine forward seal No. 2 sump forward seal (-10 engine) No. 2 sump seals (-8 engine)
[Al]	Lube pump
[Cr]	No. 1 sump mating ring (-10 engine)
[Cu]	Accessory bearing cages Power turbine right angle drive worm gears
[Cu] & Ag	Main engine bearing cages No. 3 sump static seal No. 2 sump rear seal (-10 engine)

T58-3
(H-1)

A/E 35 U-1

	Fe	Ag	Al	Cr	Cu	Mg
A	0-22	0-1	0-7	0-2	0-7	0-5
N	23-27	2	8-9	3	8	6-7
K	28-34	3	10-12	4	9-11	8-9
T	35+	4+	13+	5+	12+	10+

A/E 35 U-3

	Fe	Ag	Al	Cr	Cu	Mg
A	0-26	0-1	0-9	0-2	0-9	0-7
N	27-31	2	10-11	3	10-11	8
K	32-39	3	12-14	4	12-14	9-11
T	40+	4+	15+	5+	15+	12+

Atomic Absorption

	Fe	Ag	Al	Cr	Cu	Mg
A	0-16	0	0-5	0-1	0-3	0-3
N	17-19	1	6-7	2	4	4
K	20-24	2	8-9	3	5-6	5-6
T	25+	3+	10+	4+	7+	7+

Codes:

A – Continue routine sampling.

N – Do not change oil, submit redtagged sample after each flying day.

K – Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded.

T – Ground unit, examine for suspected discrepancy. Advise laboratory of findings.

T58-3
(H-1)

[Fe] & Cr	Accessory bearing outer race No. 3 bearing outer race No. 5 bearing outer race (-5 & -8 engines)
[Fe] & Cr Ni	Nos. 2 and 4 bearing outer race (-8 engine) No. 4 bearing outer race (-5 engine) Nos. 2, 4 and 5 bearing outer race (-10 engine)
[Fe Al] & Cr Ni	Power turbine forward seal No. 2 sump forward seal (-10 engine) No. 2 sump seals (-8 engine)
[Al]	Lube pump
[Cr]	No. 1 sump mating ring (-10 engine)
[Cu]	Accessory bearing cages Power turbine right angle drive worm gears
[Cu] & Ag	Main engine bearing cages No. 3 sump static seal No. 2 sump rear seal (-10 engine)

T76-10/12
(OV-10)

A/E 35 U-1

	Fe	Ag	Al	Cr	Cu	Mg
A	0-8	0-1	0-7	0-1	0-3	0-5
N	9-12	2	8-11	2	4-5	6-9
K	13-15	3	12-14	3	6-7	10-11
T	16+	4+	15+	4+	8+	12+

A/E 35 U-3

	Fe	Ag	Al	Cr	Cu	Mg
A	0-9	0-1	0-7	0-1	0-4	0-6
N	10-14	2-3	8-11	2-3	5-7	7-10
K	15-17	4	12-14	4	8-9	11-12
T	18+	5+	15+	5+	10+	13+

Atomic Absorption

	Fe	Ag	Al	Cr	Cu	Mg
A	0-4	0	0-3	0	0-2	0-2
N	5	1	4	1	3	3
K	6-7	2	5-6	2	4	4-5
T	8+	3+	7+	3+	5+	6+

Codes:

A – Continue routine sampling.

N – Do not change oil, submit redtagged sample after each flying day.

K – Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded.

T – Ground unit, examine for suspected discrepancy. Advise laboratory of findings.

T76-10/12
(OV-10)

SOAP-detectable failures include the high-speed pinion bearings, planetary bearings, and prop governor bearings. Any significant increase in Fe from one sample to the next indicates bearing failure. Recommend inspection of filters, screens and magnetic plugs to verify if gears or splines are involved in the failure. Increases in Mg are usually indicative of fretting in the diaphragm.

A/E 35 U-1

	Fe	Ag	Al	Cr	Cu	Mg
A	0-9	0-1	0-5	0	0-3	0-2
N	10-11	2	6	1	4	3
K	12-15	3	7-8	2	5-6	4-5
T	16+	4+	9+	3+	7+	6+

A/E 35 U-3

	Fe	Ag	Al	Cr	Cu	Mg
A	0-12	0-1	0-5	0	0-4	0-2
N	13-15	2	6-7	1	5	3
K	16-19	3	8-9	2	6-7	4-5
T	20+	4+	10+	3+	8+	6+

Atomic Absorption

	Fe	Ag	Al	Cr	Cu	Mg
A	0-5	0	0-2	0	0-1	0-1
N	6-7	1	3	1	2	2
K	8-9	2	4	2	3	3
T	10+	3+	5+	3+	4+	4+

Codes:

A – Continue routine sampling.

N – Do not change oil, submit redtagged sample after each flying day.

K – Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded.

T – Ground unit, examine for suspected discrepancy. Advise laboratory of findings.

Increases in iron and silver may be indicative of discrepancy in No. 5 bearing area.

IO-360
(0-2)

A/E 35 U-1

	Fe	Ag	Al	Cr	Cu	Mg
A	0-63	0-1	0-34	0-2	0-16	0-3
N	64-73	2	35-40	3	17-19	4
K	74-89	3	41-49	4	20-24	5
T	90+	4+	50+	5+	25+	6+

A/E 35 U-3

	Fe	Ag	Al	Cr	Cu	Mg
A	0-88	0-2	0-34	0-4	0-18	0-4
N	89-102	3	35-40	5	19-21	5
K	103-124	4	41-49	6-7	22-26	6-7
T	125+	5+	50+	8+	27+	8+

Atomic Absorption

	Fe	Ag	Al	Cr	Cu	Mg
A	0-63	0	0-20	0-3	0-16	0-3
N	64-73	1	21-24	4	17-19	4
K	74-89	2	25-29	5-6	20-24	5-6
T	90+	3+	30+	7+	25+	7+

Codes:

A – Continue routine sampling.

N – Do not change oil, submit redtagged sample after each flying day.

K – Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded.

T – Ground unit, examine for suspected discrepancy. Advise laboratory of findings.

IO-360
(O-2)

Increases in Fe and Cr are indicative of ring/cylinder wear. Increase in Cu by itself, or in combination with Fe, indicates rod and main bearing discrepancy.

R2800 - All Series
(C-118/C-131/T-29)

A/E 35 U-1

	Fe	Ag	Al	Cr	Cu	Mg
A	0-41	0-3	0-10	0-7	0-9	0-6
N	42-48	4	11-17	8-9	10-11	7
K	49-59	5-6	18-24	10-11	12-14	8-9
T	60+	7+	25+	12+	15+	10+

A/E 35 U-3

	Fe	Ag	Al	Cr	Cu	Mg
A	0-36	0-3	0-8	0-7	0-11	0-7
N	37-42	4	9-14	8-9	12-14	8-9
K	43-51	5-6	15-19	10-11	15-17	10-11
T	52+	7+	20+	12+	18+	12+

Atomic Absorption

	Fe	Ag	Al	Cr	Cu	Mg
A	0-38	0-3	0-16	0-6	0-9	0-4
N	39-44	4	17-19	7	10-11	5
K	45-54	5-6	20-24	8-9	12-14	6-7
T	55+	7+	25+	10+	15+	8+

Codes:

A – Continue routine sampling.

N – Do not change oil, submit redtagged sample after each flying day.

K – Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded.

T – Ground unit, examine for suspected discrepancy. Advise laboratory of findings.

R2800 - All Series
(C-118/C-131/T-29)

Caution must be exercised due to high oil consumption and inflight oil replenishment. Oil is frequently contaminated with water. An increase in all wearmetals is usually an indication of water contamination. Increase in Al by itself, or in combination with Fe, usually indicates discrepancy in the cylinder and rocker box area. An increase in Fe by itself is usually indicative of oil pump or pinion gear failure. If aircraft has been idle for 3 or more days, high Fe may be due to corrosion. An increase in Ag is indicative of incipient bearing wear.

A/E 35 U-1

	Fe	Ag	Al	Cr	Cu	Mg
A	0-26	0-1	0-8	0-4	0-13	0-5
F	27-30	2	9	5	14-15	6
K	31-34	3	10-11	6	16-17	7-8
T	35+	4+	12+	7+	18+	9+

A/E 35 U-3

	Fe	Ag	Al	Cr	Cu	Mg
A	0-34	0-1	0-10	0-4	0-14	0-6
F	35-39	2	11-12	5	15-16	7
K	40-44	3	13-14	6	17-19	8-9
T	45+	4+	15+	7+	20+	10+

Atomic Absorption

	Fe	Ag	Al	Cr	Cu	Mg
A	0-18	0	0-4	0-1	0-8	0-3
F	19-21	1	5	2	9	4
K	22-24	2	6	3	10-11	5
T	25+	3+	7+	4+	12+	6+

Codes:

A – Continue routine sampling.

F – Do not change oil, submit redtagged sample after every five hours of operation.

K – Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded.

T – Ground unit, examine for suspected discrepancy. Advise laboratory of findings.

Increase in Fe and Cu indicates discrepancy in starter clutch area.

[Fe] & Cr	Bearing rollers and races
[Fe] & Ni	Oil pump gears and shaft
[Fe] & Cr Ni	Turbine and aft compressor carbon seal races Turbine section bearing spacer and housing Aft compressor section shaft and bearing mount Accessory assembly carbon seal rotors, gears, shafts, bearing housing, retainers and carriers Output geardrive seal runners and bearing retainer gasket seals Forward compressor assembly shaft and inlet compressor seal races
[Cu]	Oil pump bushings
[Cu] & Ag	Turbine section bearing cages
[Cu] & Sn	Output geardrive bearing cages Aft compressor section bearing cages Oil pump gear pins
[Cu] & Ag Sn	Accessory assembly bearing cages
[Al] & Cu	Forward compressor assembly bearing and seal housing Oil pump body, cover and plate assembly
[Mg]	Accessory case assembly
[Al] Mg	Output geardrive housing
[Al] & Ni Cr	Output geardrive gears
[Ni] & Cr Fe	Turbine wheel shaft
[Sn] & Fe Cu	Forward compressor assembly sleeve bearing

A/E 35 U-1

	Fe	Ag	Al	Cr	Cu	Mg
A	0-19	0-2	0-5	0-4	0-11	0-4
F	20-29	3	6-8	5-6	12-17	5-6
K	30-39	4-5	9-11	7-9	18-24	7-9
T	40+	6+	12+	10+	25+	10+

A/E 35 U-3

	Fe	Ag	Al	Cr	Cu	Mg
A	0-19	0-3	0-6	0-5	0-6	0-5
F	20-29	4-5	7-10	6-8	7-10	6-8
K	30-39	6-7	11-14	9-11	11-14	9-11
T	40+	8+	15+	12+	15+	12+

Atomic Absorption

	Fe	Ag	Al	Cr	Cu	Mg
A	0-11	0-1	0-3	0-3	0-3	0-2
F	12-14	2	4	4	4-5	3
K	15-17	3	5-6	5	6-7	4
T	18+	4+	7+	6+	8+	5+

Codes:

A – Continue routine sampling.

F – Do not change oil, submit redtagged sample after every five hours of operation.

K – Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded.

T – Ground unit, examine for suspected discrepancy. Advise laboratory of findings.

Increase in Fe and Cu indicates discrepancy in bearing area.

[Fe] & Cr	Bearing rollers and races
[Fe] & Ni	Oil pump gears and shaft
[Fe] & Cr Ni	Turbine and aft compressor carbon seal races Turbine section bearing spacer and housing Aft compressor section shaft and bearing mount Accessory assembly carbon seal rotors, gears, shafts, bearing housing, retainers and carriers Output geardrive seal runners and bearing retainer gasket seals Forward compressor assembly shaft and inlet compressor seal races
[Cu]	Oil pump bushings
[Cu] & Ag	Turbine section bearing cages
[Cu] & Sn	Output geardrive bearing cages Aft compressor section bearing cages Oil pump gear pins
[Cu] & Ag Sn	Accessory assembly bearing cages
[Al] & Cu	Forward compressor assembly bearing and seal housing Oil pump body, cover and plate assembly
[Mg]	Accessory case assembly
[Al Mg]	Output geardrive housing
[Al] & Ni Cr	Output geardrive gears
[Ni] & Cr Fe	Turbine wheel shaft
[Sn] & Fe Cu	Forward compressor assembly sleeve bearing

GTCP165-1
(C-5 APU)

A/E 35 U-1

	Fe	Ag	Al	Cr	Cu	Mg
A	0-26	0-2	0-8	0-2	0-13	0-30
N	27-30	3	9	3	14-15	31-34
K	31-34	4	10-11	4	16-17	35-39
T	35+	5+	12+	5+	18+	40+

A/E 35 U-3

	Fe	Ag	Al	Cr	Cu	Mg
A	0-30	0-2	0-10	0-2	0-14	0-37
N	31-34	3	11-12	3	15-16	38-43
K	35-39	4	13-14	4	17-19	44-49
T	40+	5+	15+	5+	20+	50+

Atomic Absorption

	Fe	Ag	Al	Cr	Cu	Mg
A	0-14	0	0-5	0	0-6	0-18
N	15-16	1	6	1	7	19-21
K	17-19	2	7	2	8-9	22-24
T	20+	3+	8+	3+	10+	25+

Codes:

A – Continue routine sampling.

N – *Do not change oil, submit redtagged sample* after each flying day.

K – Submit redtagged sample as soon as possible. Suspect possible discrepancy due to increasing wearmetal trends, recommend maintenance inspection, unit not grounded.

T – *Ground unit, examine for suspected discrepancy.* Advise laboratory of findings.

GTCP165-1
(C-5 APU)

APPENDIX C

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This report presents the results of a study of the U.S. Air Force Spectrometric Oil Analysis Program. The study consisted of review, evaluation, and documentation of data for revision of the Technical Manual Spectrometric Oil Analysis Program (SOAP) Evaluation Criteria (T.O.42B2-1-10). The purpose of the revision is to provide the SOAP laboratory analyst with more positive guidance, and to ensure ease of use of the evaluation criteria for the equipments considered in this study. The report covers development of a methodology, data collection, data analysis, and formulation of evaluation criteria. Specific problem areas

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observed during the study are identified, and recommendations for their solution are presented.